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PENNSYLVANIA
GEOLOGICAL SURVEY
FOURTH SERIES

OIL RESOURCES IN COAL AND CARBONACEOUS SHALES OF PENNSYLVANIA

BY
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DEPARTMENT OF INTERNAL AFFAIRS
James F. Woodward, Secretary

BUREAU OF TOPOGRAPHIC AND GEOLOGICAL SURVEY

George H. Ashley, State Geologist

1923

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By James F. Woodward
Secretary, Department of Internal Affairs
for the
Commonwealth of Pennsylvania

LETTER OF TRANSMITTAL.

Mr. James F. Woodward,

Secretary of Internal Affairs:

I have the honor to transmit herewith the manuscript and illustrations for a paper describing the oil resources in coals and carbonaceous shales of Pennsylvania by Charles R. Fettke, Associate Professor of Geology and Mineralogy, Carnegie Institute of Technology.

It is well recognized today that the supply of oil from oil wells is limited and is rapidly being exhausted. As the supply from this source declines, recourse must be had to other sources of oil. These other sources are the bituminous coals and oil shales. The paper herewith submitted describes some very complete studies of the coals of Pennsylvania and of such carbonaceous shales as seem to offer possibilities for oil production.

Respectfully,

Geo. H. Ashley

May 1923

State Geologist.

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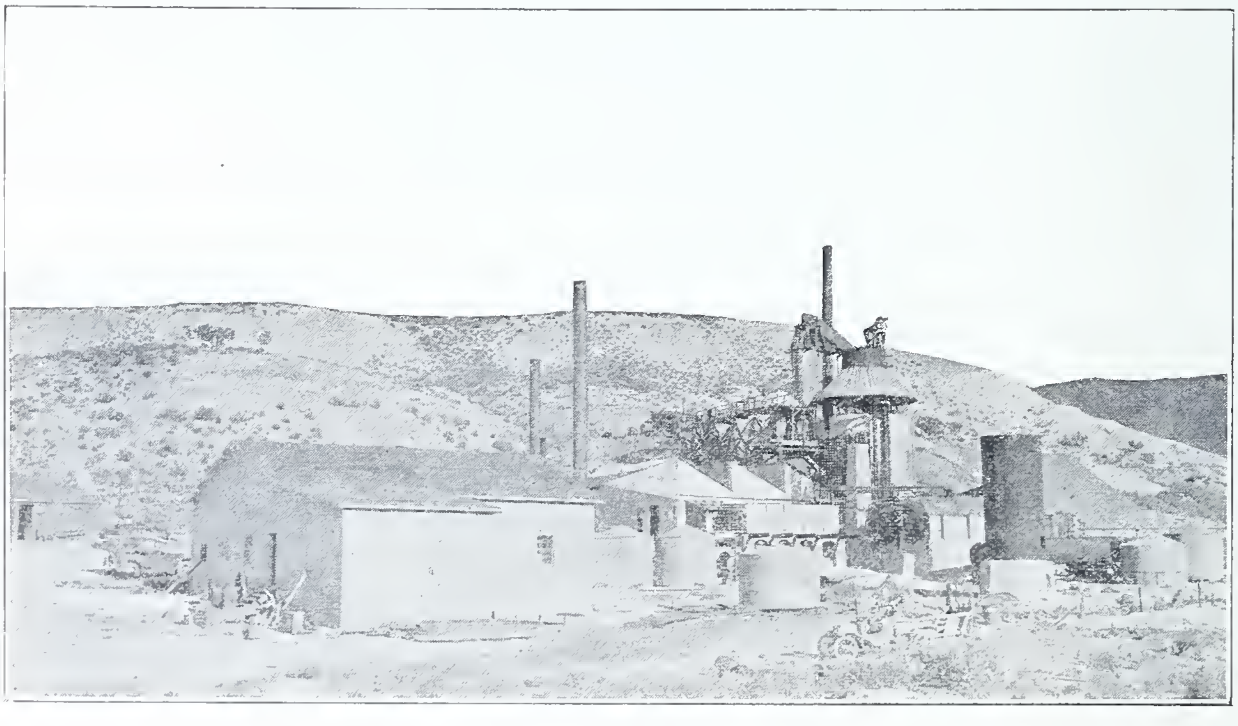
A. Dump of spent cannel coal and shale at site of old "coal oil" distillery, Cannelton, Pa.



B. Mine and oil distillation plant of Catlin Shale Products Company, 1½ miles southwest of Elko, Nevada.

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OIL RESOURCES IN COALS AND CARBONACEOUS SHALES OF PENNSYLVANIA

INTRODUCTION.

Petroleum in recent years has become one of the basic necessities in the life of the nation. This has come about largely through the development of the internal combustion engine and the substitution of oil for coal as fuel in steam plants. Petroleum now stands second in value among the mineral products of the United States—coal being first. In 1920 the United States produced 443,402,000 barrels, of 42 gallons each, valued at $1,360,000,000.[1]

Petroleum and the products derived from it have become so intimately interwoven with the industrial, commercial, and social fabric of the nation that it is extremely difficult to imagine how we could possibly dispense with them. The present era has frequently been spoken of as the "Age of Petroleum." Unfortunately the unmined reserves of this great natural resource in the United States are being rapidly depleted, and one of the problems that will have to be faced within the next decade or two will be the finding of substitutes for petroleum products in continually growing quantity.

Coal and so-called oil shales, when subjected to low temperature destructive distillation or carbonization, yield oils which, in some respects, are similar to petroleum. Substances can be obtained from these oils that in many instances will answer the same purposes as those now derived from petroleum. Coal and oil shales, which are rich in organic matter, have, therefore, attracted considerable attention in recent years as a possible future source of such substitutes.

On account of the importance and enormous possibilities of such an industry in the comparatively near future, the Topographic and Geological Survey of Pennsylvania in 1917, through Richard R. Hice, then State Geologist, engaged the writer to gather the data and prepare a report on the oil possibilities of the coals and carbonaceous shales of the State. Field work was begun early in the spring of 1918 and preliminary tests on the samples collected were started that fall, but stopped by lack of funds. The work was taken up again early in 1920 under the direction of George H. Ashley, the present State Geologist.

The necessary experiments in connection with the investigation have been conducted in the geological and mineralogical laboratories of the Carnegie Institute of Technology, of Pittsburgh. For assistance rendered in carrying on the work, the writer wishes to express his thanks to the owners and officers of the various companies whose mines were visited during the course of the investigation. He is also greatly indebted for many valuable suggestions to the numerous fellow-workers at present engaged in the study of oil shales, with whom he has had an opportunity to discuss some of the problems involved, particularly Messrs. J. D. Davis, Martin J. Gavin, Lewis C. Karrick, and Dr. Reinhardt Thiessen, of the U. S. Bureau of Mines, Leslie H. Sharp, of the Colorado Co-operative Oil Shale Laboratory, Professor R. D. George, State Geologist of Colorado, Professor Arthur J. Franks, of the Colorado School of Mines, and C. L. Jones, of the Mellon Institute of Pittsburgh. Through a cooperative agreement with the Pittsburgh Station of the U. S. Bureau of Mines, proximate and ultimate

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1. Preliminary Summary, U. S. Geol. Survey Mineral Resources, 1920, p. 91, 1921.

analyses of eleven samples of coal and shale were made for the writer in the coal laboratories of that organization.

CHAPTER I.

THE PETROLEUM SITUATION.

In order to discuss intelligently the possibilities of the commercial development of an oil industry based upon the carbonization of coals and shales, an understanding of the present petroleum situation is necessary. For that reason a brief survey of the magnitude of the petroleum industry in the United States, as well as the size of the unmined reserves upon which it can expect to draw in the future, are included in this report. Some knowledge of the properties of petroleum and of the various products derived from it and of their uses is also essential.

Petroleum Resources of the United States and the World.

The rapid increase in the demand for petroleum and its products during the past two decades is well brought out by the production curve shown in Figure 1, prepared from statistics published by the United States Geological Survey. For the sake of comparison, Figure 2, showing the total production of coal in the United States during the corresponding period, has been introduced. In spite of the fact that the oil wells of the United States in 1920 yielded a total of 443,402,-000 barrels the supply was not sufficient to satisfy the demand and 106,175,289 barrels of crude were imported.[1]

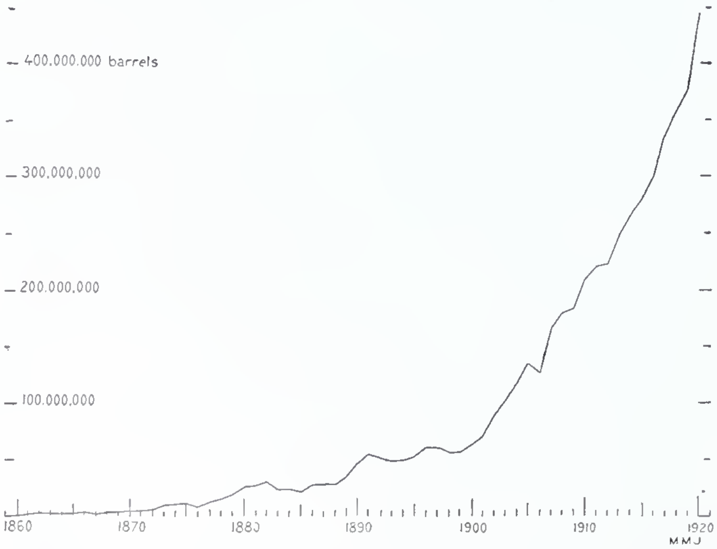

Figure 1. Petroleum production curve for the United States, 1859 to 1920 inclusive.

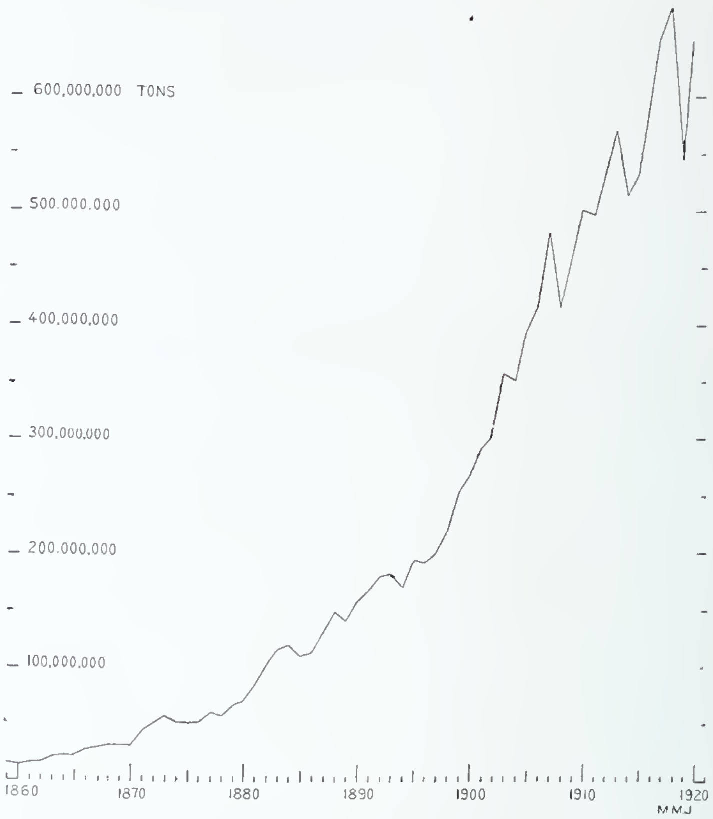

Figure 2. Coal production curve for the United States. 1859 to 1920 inclusive.

An outstanding feature of the petroleum curve is the sharp increase shown in the rate of production which occurred at the beginning of the present century, coincident with the appearance of the automobile, and which has continued with only minor fluctuations to the present day. A comparison with the curve for coal shows that its consumption has also increased rapidly during the same time, due to the enormous industrial expansion in the United States; with this difference, that the sharp increase antedates that of petroleum by at least two decades. The fluctuations in coal production from year to year are also much more pronounced than those of petroleum, due undoubtedly to the fact that during times of business depression a coal mine can be shut down while an oil well, that has once been brought in, or an oil field, whose development has been commenced, cannot cease production without serious financial loss.

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[1] Preliminary Summary. U. S. Geol. Survey Mineral Resources. 1920, p. 92. 1921.

The petroleum production of the United States in all probability will reach its crest within the next five years, if it has not already done so, and a gradual decline may be expected, due to the rapid depletion of the unmined reserves; while there is no reason to believe that the annual production of coal will not continue to increase for a long time to come, as the nation's industrial resources are still further developed and population increases. The coal reserves are many times greater than those of petroleum.

Estimates made by a committee composed of members of the American Association of Petroleum Geologists and of the United States Geological Survey, place the unmined reserve of petroleum, recoverable by methods now in use, that still remained in this country on January 1, 1922 at nine billion barrels in round numbers. Of this total, five billion barrels may be classified as oil in sight and four billion barrels as prospective and possible. More than four billion barrels should be assigned to the heavy oil group, while the remaining five billion barrels may be classed as so-called paraffin oil of medium and high grade.

At the present rate of consumption the estimated reserve would last only twenty years if the oil could be taken out of the ground as fast as it is wanted. This is not possible, however, because many wells drilled now or in the future cannot be pumped dry within that interval, nor will all of the still undiscovered and undeveloped oil pools be found within that period. Although a marked decline in the production will, therefore, take place in the near future, oil will be produced from wells in the United States for a long time to come but in steadily diminishing quantities. This constantly increasing difference between production and demand will have to be taken care of by more efficient utilization of the petroleum produced, by the importation of larger quantities of oil from foreign sources, and by the production from other sources of products now derived from petroleum. Substitutes may be derived, for example, by the recovery of oils through the carbonization of coals and oil shales, of both of which the United States possesses enormous reserves.

It must also be kept in mind that the above estimated reserves, which are based upon present modes of production, can be greatly increased by more efficient methods of recovery. Lewis[1] believes that the recovery in the past has been less than 20 per cent of the total oil sand contents and that this can be increased by at least half and perhaps by as much again as is now produced. This will of course greatly increase the available reserves.

In connection with estimates that have been made for the United States, it is interesting to note that White[2] believes that there are still available the world over about 60 to 70 billion barrels of petroleum, about half of which occurs in the Western Hemisphere. These figures are based on data gathered by himself and colleagues on the U. S. Geological Survey. The world's production of crude petroleum in 1919 was 541,885,000 barrels, of which 377,719,000 or 69 per cent was produced in the United States.[3]

---

[1] Lewis J. O., America's Petroleum Problems. Jour. of the Franklin Institute. Vol. 191, pp. 357-379, 1921.

[2] White, David. The Petroleum Resources of the World, Annals of the Am. Acad. of Political and Social Science. Vol. 89, pp. 111-134, 1920.
The Oil Supply of the World. Eng. and Min. Jour., Vol. 113, pp. 155-156. 1922.

[3] Preliminary Summary, U. S. Geol. Survey Mineral Resources 1920, p. 92. 1921.

Composition of Petroleum.[1]

Crude petroleum is a naturally occuring liquid consisting principally of a number of series of hydrocarbons, belonging to the aliphatic, aromatic, and hydroaromatic or naphthene groups, with admixtures of sulphur, nitrogen, and oxygen derivatives in comparatively minute proportions. All hydrocarbons may be grouped under a number of regular series to which generalized formula may be assigned. Members of the following of these series have been found in petroleum, the first five being the most important:—

1. $C_nH_{2n}+2$
2. C_nH_{2n}
3. $C_nH_{2n}-2$
4. $C_nH_{2n}-4$
5. $C_nH_{2n}-6$
6. $C_nH_{2n}-8$
7. $C_nH_{2n}-10$
8. $C_nH_{2n}-12$
9. $C_nH_{2n}-14$

The series $C_nH_{2n}+2$ is commonly known as the methane, marsh gas, or paraffin series from the fact that methane or marsh gas, CH_4, is the first member and paraffin wax consists primarily of the higher members of the series ranging from $C_{20}H_{42}$ to $C_{35}H_{72}$. This series belongs to the aliphatic or open chain group of carbon compounds. Its hydrocarbons preponderate in petroleums from the Appalachian field.

There are two series of hydrocarbons which have the general formula C_nH_{2n}. The first, commonly known as the olefine or ethylene series, consists of unsaturated open chain hydrocarbons; while the second, known as the polymethylene or naphthene series, contains cyclic or closed chain compounds. Members of the olefine or ethylene series are probably present in most petroleum but, as a rule, only in very small quantity. They are dissolved by the acid in refining the crude distillate. The naphthene hydrocarbons are probably also present in all petroleum to a certain extent, in small quantity in the light oils from the Appalachian fields, and in larger proportions in the heavy sulphur and asphaltic varieties. Russian petroleum consists principally of hydrocarbons of this series.

The next two series, $C_nH_{2n}-2$ and $C\,H_{2n}-4$, comprise unsaturated cyclic hydrocarbons, members of which are found in all petroleum but are present in much larger proportions in the heavy asphaltic varieties than in the lighter oils which have a paraffin base. Mabery believes that the lubricating power in prepared oils is due to hydrocarbons belonging to these two series, but all petroleum chemists do not concur with him in this.

Hydrocarbons of the series $C_nH_{2n}-6$, the aromatic or benzene series, are present in nearly all petroleums, but usually in subordinate amounts, particularly in the lighter grades such as those of the Appalachian fields. Some heavier grades, especially those from the California fields, contain much larger quantities. According to Mabery, these compounds are rather a detriment to petroleum to be removed in the process of refining.

Small quantities of oxidized bodies, of which complex acids and phenols are examples, are contained in many petroleums. They have no influence on commerical products as they are removed by proper refining, although it is possible that they may have something to do with the formation of emulsions.

Nitrogen is present in nearly all petroleum, varying in quanity from a trace up to one per cent and over. It exists in most cases in the form of complex organic bases, usually pyridine and quinoline derivatives. Some California petroleums contain as high as 10 to 20 per cent of these bases.

Sulphur is the most undesirable impurity in petroleum, but the amount is commonly very small. Rarely it is entirely absent. Much Pennsylvania crude contains less than .1 per cent; some oils from Texas and Wyoming have been known to contain as much as 2.6 to 2.75 per cent. Sulphur may be present in petroleum as hydrogen sulphide, as free sulphur, or as organic sulphur compounds. The first two are not hard to remove. Organic sulphur, on the other hand, is much more difficult to eliminate even though present only in small quantity.

---

[1] Bacon, R. F. and Hamor, W. A., The American Petroleum Industry. Vol. 1, New York, pp. 1-8, 1916.
Tinkler, C. K., and Challenger, F., The Chemistry of Petroleum and its Substitutes, London, pp. 62-66, 1917.
Clarke, F. W., The Data of Geochemistry, 4th eidtion, [U. S. Geological Survey Bull. 695, 1920.
Mabery, C. F., Composition of Petroleum and its Relation to Industrial Use. Trans. Am. Inst. Min. and Met. Eng., Vol. LXV pp. 505-521, 1921.

Petroleums from different fields vary widely in their composition, but since no single variety is entirely free from hydrocarbons contained in others, it is difficult to make a classification. A commercial distinction is usually made between oils with a paraffin base, such as those obtained from the Appalachian fields, and oils with an asphaltic base, typical of the Gulf Coast and California fields. This distinction, however, cannot be very closely drawn because many oils, as, for example, those obtained from the mid-continent field, contain both constituents.

In the following table are given figures representative of the refining properties of a number of crude oils produced in various parts of the United States, as determined in the petroleum laboratories of the U. S. Bureau of Mines:[1]—

Approximate refining properties of crude oils from several States.

State	Penna.	W. Va.	Ohio	Kentucky	Illinois	Oklahoma	Wyoming	Wyoming	California
County	Composite a.	Composite b.	Allen	Composite a.	Composite b.	Creek	Natrona	Freemont	Kern
Field		Eureka	Lima			Cushing	Salt Creek	Maverick	Maricopa
Crude Oil									
Sp. Gr.,	0.811	0.805	0.835	0.835	0.863	0.828	0.841	0.922	0.878
Deg. Baume′,	42.6	43.9	37.7	37.7	32.2	39.1	36.5	21.8	29.5
Sulphur per cent,	0.08	0.10	0.55	0.23	0.24	0.12	0.18	2.46	0.73
Gasoline									
Per cent,	33.9	31.3	31.0	35.4	20.4	37.5	29.3	8.6	21.5
Sp. Gr.,	0.734	0.739	0.749	0.735	0.769	0.743	0.750	0.765	0.789
Deg. Baume′,	60.7	59.4	56.9	60.5	52.1	58.4	56.7	53.0	47.4
Kerosene									
Per cent,	19.9	18.5	19.2	16.2	14.5	18.0	15.7	14.7	18.8
Sp. Gr.,	0.802	0.799	0.815	0.824	0.834	0.818	0.824	0.824	0.866
Deg. Baume′,	44.6	45.2	41.8	39.9	37.9	41.1	39.9	39.9	31.7
Gas Oil									
Per cent,	9.7	12.1	9.9	9.3	8.0	11.5	10.8	10.9	----------
Sp. Gr.,	0.835	0.825	0.843	0.851	0.856	0.855	0.847	0.869	----------
Deg. Baume′,	37.7	39.7	36.1	34.5	33.6	33.7	35.3	31.1	----------
Light Lubricating Distillate									
Per cent,	11.1	11.0	10.7	9.5	10.7	9.6	11.1	13.7	8.7
Sp. Gr.,	0.852	0.844	0.870	0.874	0.877	0.876	0.865	0.901	0.908
Deg. Baume′,	34.3	35.9	30.9	30.2	29.6	29.8	31.9	25.4	24.2
Medium Lubricating Distillate									
Per cent,	6.3	5.6	5.5	4.6	6.0	4.7	5.8	8.0	10.9
Sp. Gr.,	0.865	0.856	0.890	0.894	0.803	0.896	0.880	0.924	0.930
Deg. Baume′,	31.9	33.7	27.3	26.6	26.8	26.3	29.1	21.5	20.5
Viscous Lubricating Distillate									
Per cent,	----------	----------	----------	----------	----------	----------	----------	----------	6.3
Sp. Gr.,	----------	----------	----------	----------	----------	----------	----------	----------	0.946
Deg. Baume′,	----------	----------	----------	----------	----------	----------	----------	----------	18.0
Carbon residue in residuum,	3.2	1.9	6.2	7.2	10.6	6.8	6.1	17.9	16.4

a. From several counties.
b. From Lawrence, Crawford and other counties.

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[1] U. S. Bureau of Mines, Reports of Investigations, Serial Nos. 2202, 2235, 1921.

Petroleum Products and Their Uses.

A wide range of commodities is obtained from petroleum, of which gasoline, kerosene, fuel oil, and lubricating oils are of major importance. Pogue has prepared the following table showing the most important ones:—

Major products	Principal varieties
Gasoline	Aviation gasoline Motor gasoline Benzine Naphtha
Kerosene	Water-white Standard-white Mineral seal Distillate
Fuel oil	Gas oil Residual fuel oil
Lubricating oils	Neutral oils Cylinder stocks Paraffin oils
Primary by-products	Paraffin wax Asphalt Road oil Petroleum coke
Secondary by-products (fabricated)	Greases Petrolatum Medicinal oils, etc.

The relative importance of these is brought out by the following table complied by Pogue[1] from data furnished by the Bureau of Engineering, Oil Division, U. S. Fuel Administration, which is based upon the estimated average returns per barrel of crude petroleum refined in the United States in 1918:—

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[1] Pogue, Joseph E., The Economics of Petroleum. New York, p. 89, 1921.

Rank	Product	Dollars	Per cent of total
1.	Gasoline	1.922	44.5
2.	Gas and fuel oil	1.213	28.2
3.	Lubricating oils	.419	9.7
4.	Kerosene	.378	8.8
5.	Wax	.121	2.8
6.	Asphalt	.042	0.95
7.	Coke	.0069	0.15
	All others	.210	4.9
		4.3119	100.00

The quantities of these different products turned out by the petroleum refineries in the United States during 1918 were as follows:[1]

Crude petroleum run	326,024,630	barrels
Oil purchased and re-run	50,565,204	barrels
Gasoline	3,570,312,963	gallons
Kerosene	1,825,360,137	gallons
Gas and fuel oil	7,321,397,557	gallons
Lubricating oils	841,465,767	gallons
Wax	505,144,357	pounds
Coke	559,633	short tons
Asphalt	607,968	short tons
Miscellaneous	1,286,710,383	gallons
Losses	14,556,625	barrels

To the above should be added 282,535,550 gallons of natural-gas gasoline recovered from natural gas in 1918.[2]

In 1920 the volume of these various products in round numbers and their relative importance, according to statistics compiled by the U. S. Bureau of Mines, was as follows:[3]

Petroleum products in 1920.

Product	Millions of barrels	Per cent
Gasoline	116.2	24.5
Kerosene	55.2	11.7
Gas and fuel oil	211.3	44.6
Lubricating oils	24.9	5.3
All others	47.7	10.0
Losses	18.7	3.9
	474.0	100.0

These various products are obtained from petroleum by a process of distillation, either with or without the use of steam, by means of which successive fractions are vaporized and separately condensed, the resulting distillates being then redistilled and chemically purified to yield the finished products of commerce. Certain of the compounds which decompose at temperatures of vaporization are removed as residual bodies, instead of as distillates.

Gasoline.

Due to the extraordinarily rapid growth of the automotive industry, gasoline has come to be the most important in point of value of the products manufactured from petroleum. While the increase in crude oil production during the past decade has been 142 per cent, the increase in gasoline production has been over 700 per cent. In 1920 approximately 25 per cent of the petroleum run to the stills was converted into gasoline. Commercial gasoline, as prepared today, is composed of straight-run gasoline; natural-gas gasoline recovered from natural gas; synthetic gasoline made by "cracking" heavier petroleum distillates, such as gas oil; and naphthas, representing some of the lighter fractions of kerosene which can only be used by blending with the more volatile types of gasoline, such as those derived from natural gas. Cross[4] estimates that straight-run gasoline constitutes about 70 per cent of the total production of the United States at the present time. The next most important source is synthetic or "cracked" gasoline which supplies about 23 per cent of the total. The next greatest source is the light gasoline obtained from natural gas. This amounts to about 5 per cent of the total. Light oils from by-product coke and coal gas plants furnish the remaining 2 per cent. The latter three varieties are not used separately but are blended with the straight-run variety to make a commercial product.

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1. U. S. Geol. Survey Mineral Resources 1918, Part II p. 1127, 1921.
2. Mineral Resources, op. cit., p. 1408, 1921.
3. Pogue, Joseph E., op. cit., p. 289.
4. Cross, Roy, Production of Synthetic Gasoline, Oil and Gas Journal March 10, 1922, p. 74.

Gasoline consists primarily of a series of related hydrocarbon compounds ranging from light volatile components, through graded intermediates, to relatively heavy, less volatile end-products. As the demand for gasoline has been steadily increasing, there has also been a gradual rise in the end-point, or, in other words, a decrease in its volatility, due to the fact that the refiners have had to cut further and further into the kerosene fraction in order to keep up with the growing consumption of gasoline. In January, 1921 the end-point of the gasoline sold in the leading cities of the United States had reached 220° C. or 429° F.[1] The gasoline of today is also beginning to contain appreciable percentages of unsaturated compounds, such as members of the olefine series, some gasoline sold in New York City running as high as 20 per cent.[2] This is primarily due to the blending of increasing amounts of "cracked" gasoline with the straight-run product. According to McKee, "cracked" gasoline carries up to 40 per cent of unsaturated hydro carbons. The presence of these compounds causes gasoline on standing in contact with air to discolor and after a time, due to polymerization, small amounts of brown gum or tarlike substances separate out. These may cause motor trouble if formed in too large quantities.

At the present time, over 90 per cent of the gasoline produced in the United States is consumed by passenger automobiles, trucks, and tractors, or goes into the export trade. The latter amounts to approximately 14 per cent of the total production. The use of gasoline for cleaning, solvent purposes, and chemical manufacture has become relatively unimportant.

Kerosene.

Kerosene is the second product separated in the distillation of crude oil. At one time it was the mainstay of the oil-refining industry, but through the enormous increase in the demand for gasoline, it has been relegated to a relatively subordinate position. In 1920, only 11.7 per cent of the crude oil run to the stills was converted into kerosene, as contrasted with 58 per cent in 1899.[3]

Kerosene is still used mainly for purposes of illumination and heating, although in recent years steadily growing quantities have been employed for power purposes in tractors, motor-boats, and stationary engines. About one-third of the output is exported.

The main reason for the decline in kerosene production has been the diversion of the lighter fractions to the manufacture of gasoline, and all indications point toward still deeper inroads for this purpose. Thus far no kerosene has been cracked into gasoline on a commercial scale.

Fuel Oil.

Fuel oil, in an economic sense, may be considered as the residue left over from the country's petroleum output after the demands for the other products have been satisfied. It includes several varieties. A certain percentage of the heavy asphaltic crude oils is used directly as fuel oil with very little preparation. Another variety is the residuum left after the more volatile fractions of the crude oil, namely the gasoline and kerosene, have been removed. It is produced mainly by skimming and topping plants. A third type, usually called gas oil, represents an intermediate distillate between kerosene and lubricating oils and is produced by refineries which recover the latter products from the crude oil.

In 1920, 44.6 per cent by volume of the crude oil run to the stills was turned out in the form of gas and fuel oil. Pogue[4] has classified the uses to which gas and fuel oil were put in 1918 as follows:

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1. Pogue, Joseph E. op. cit. p. 113.
2. McKee, Ralph H. Chemical Age, New York, Jan. 1922, p.1.
3. Pogue, Joseph E. op. cit. pp. 130-131.
4. Pogue, Joseph E. op. cit. p. 155.

Distribution of gas and fuel oil in 1918.

	Barrels.
Exported	30,000,000
Bunker oil	6,000,000
Merchant marine (1919)	31,000,000
Navy	5,000,000
Pacific Coast railroads	24,000,000
Other railroads	12,000,000
Oil field fuel	5,000,000
Gas oil used in gas manufacture	16,000,000
Industries west of Rockies	36,000,000
Industries east of Rockies	50,000,000
	215,000,000

This total was made up of 43,000,000 barrels of crude oil used as fuel directly and 172,000,000 barrels of gas and fuel oil marketed by refineries.

Most of the above enormous consumption of fuel oil is still being used as a substitute for coal for firing under boilers to generate steam. There is a growing tendency, however, to generate power with this valuable liquid fuel by means of the Diesel and semi-Deisel type of engines, by which its capacity for doing work is multiplied by three.[1]

A greatly increasing demand for fuel oil by marine transportation can be looked for on account of the advantages derived from liquid fuel in the place of coal in case of bunkering, flexibility in operation, increase in radius of steaming, and conserving labor in firing. The merchant marine of the world is being rapidly converted from coal-burning to oil-burning. By the installation of the Diesel tpye of engines, the advantage of oil over coal is still further accentuated, as the efficiency obtained is 2½ to 3 times as great as the most modern type of steam equipment.

Lubricating Oils.

Two fundamental types, namely, residual lubricating oil, known as cylinder stock, and distillate lubricating oil are the source of the numerous grades of lubricating oils made from petroleum that are on the market.

Residual lubricating oil, or cylinder stock, is made from paraffin-base and mixed-base crudes by steam distillation only. It consists of the residue left after the gasoline, kerosene, gas oil, and lubricating distillates have been removed from these oils. Asphaltic petroleums do not produce cylinder stock, since their entire lubricating content may be distilled off, leaving a residue of asphalt instead of cylinder stock.

Cylinder stock on account of its relatively high resistance to heat, is used for the lubrication of steam cylinders. The distillate types of lubricating oils are not satisfactory for this purpose. Cylinder stock is also highly viscous or heavy bodied as compared with the distillate types made from paraffin and mixed-base crudes, and hence is in demand as a blending agent for giving the requisite body to the latter where they are to be used for the lubrication of heavy service engines, machines, and motors.

There are three main varieties of distillate lubricating oils, namely:—non-viscous neutrals, made from all three types of crude petroleum by steam distillation; viscous neutrals of heavier body than the non-viscous neutrals, also made from all three types of crude by steam distillation; and paraffin oils, made from paraffin-base and mixed-base petroleum by destructive distillation without the use of steam.

The non-viscous neutrals are light-bodied and have relatively low-viscosity and hence are only suitable for the lubrication of light machinery, such as the spindles of textile mills. For the general run of lubricating service, they must be more viscous oils. They are at present produced in greater quantity than required for running light machines and as the demand is not strong, the price is relatively low.

The viscous neutrals possess a heavier body than the non-viscons. Those obtained from the asphaltic-base crudes, being comparable in body to cylinder stock, excell the ones obtained from paraffin or mixed-base crudes in this respect

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[1] Little, Arthur D., The fuel problem, Atlantic Monthly, February, 1921, pp. 190-199.

The viscous neutrals of paraffin origin lack sufficient body for heavy-service lubrication and hence for many purposes are blended with cylinder stock, while those of asphaltic origin may be used in unblended form for this purpose.

The so-called paraffin lubricating oils are somewhat inferior in quality to the cylinder stocks and neutrals, due to their method of manufacture.

There has been a steadily increasing demand for lubricating oils, chiefly of the heavier-bodied varieties. This has been brought about in part by the industrial growth of the country but chiefly by the phenomenal growth of automotive transportation. The latter is gradually demanding heavier and heavier bodied lubricants, as the lubricating oil in service is being subjected to more and more dilution or thinning as the gasoline employed is rising in end-point. At present, approximately one-quarter of the country's total output of lubricants is used for automotive purposes and is nearly equal to the entire domestic industrial consumption. The United States exports large quantities of lubricants. It has been estimated that nearly one-third of our output of lubricating oil is sent abroad.

Future Outlook for Petroleum Products.

The unmined reserves of petroleum still remaining underground in the United States have been estimated at nine billion barrels, while those of the whole world are placed at 60 to 70 billion barrels. It is very evident that the United States, which in 1919 produced 69 per cent of the world's total output of crude oil and which has produced over 60 per cent of the petroleum brought to the surface to date, cannot hope to continue to hold her present dominating position in the petroleum industry much longer. Gradually the lead will pass to other nations that have thus far used their oil reserves less prodigally. This will bring about important economic changes in the petroleum industry in this country.

The maximum annual production will be reached within the next few years, if it has not already been done. After that a gradual decline will set in with the production slowly tapering to an end in 50 or possibly 75 years. With the present enormous annual consumption and its tendency to increase still further, exhaustion of the supply is bound to happen even if the estimates of reserves are as much as 25 or 50 per cent too low.

After the low point of the present business depression has once been passed, it is likely the demand for petroleum products the world over will again increase. As a result, a condition will soon be reached when the production of domestic crude will not be sufficient to meet the demands for petroleum products, particularly since such a condition already existed for certain of these just prior to the present crisis (1922).

The situation arising out of the impending shortage in domestic supply of crude petroleum will undoubtedly be met in a number of different ways. Larger quantities of crude oil will be imported from foreign countries and the proportion of American petroleum products shipped abroad will decline. More efficient methods of extracting the petroleum from the sands will undoubtedly come into use, resulting in an increase in the estimated reserve. New methods, such as "air pressure", "water drive", "gas pressure", and "vacuum extraction", which thus far have been employed only on a relatively small scale, will be applied in fields that are now considered practically exhausted. Eventually underground mining methods, similar to those that have been employed on a limited scale at Pechelbronn, in Alsace, may even be resorted to in the case of shallow sands to recover the 80 or so per cent of residual oil which cannot be obtained by ordinary methods. Much more attention will be paid to the elimination of waste in production.

As the production wanes and the price of crude rises higher and higher, the essential uses for petroleum products must have priority. They will be aided in obtaining this in part by being in a position to pay a higher price.

The most valuable product at present obtained from petroleum is gasoline. This commodity is absolutely essential to the automotive industry. The tremendous expansion of automotive transportation is one of the outstanding features of the twentieth century, and there is no indication that it has reached its limits. Automobiles, trucks, tractors, and air planes will surely consume continually increasing amounts of gasoline. Eventually the use of pleasure automobiles may have to be curtailed if in the meantime other sources of motor fuel are not developed in sufficient quantity and at reasonable cost. It is difficult to see how trucks, which have become such an important part of our distributing system, and tractors, which are beginning to play such an important role in the solution of the farm labor problem, can be dispensed with and what can be substituted for them.

Refiners in the past have met the increasing demands for gasoline by increasing the average boiling point of the gasoline, by extracting liquid hydro-carbons from natural gas and blending them with a portion of the lighter kerosene fractions, and by cracking a portion of the heavier fractions ordinarily sold as gas and fuel oil. In the first method the limit has probably been reached unless the design of the present automobile engine is changed. The second source also has practically been developed to its fullest possibilities, as natural gas is a resource which is dwindling even more rapidly than petroleum. The third mode of augmenting the gasoline supply offers further possibilities. Only the lighter varieties of ditillate fuel oil, such as gas oil, are suitable for cracking. About 30 to 40 per cent of the original material subjected to the process is converted into gasoline in current commercial practice, the balance being converted into a residuum suitable for fuel and coke. With present practice about half of the fuel oil output of the refineries is suitable for cracking. The oils that are available also make ideal fuel for the Diesel and semi-Diesel type of engines and as these are still further developed, particularly for marine purposes, they will draw more and more heavily on this source and will hence come more and more into competition with the gasoline type of engine. Changes in the present type of automobile engine permitting it to use fuels of higher average boiling and end-point and improvements leading to greater efficiency in combustion are other factors that will tend to conserve the gasoline supply.

Finally, there are the possibilities of obtaining motor fuel from other sources than petroleum, among which may be mentioned benzol from the by-product coke industry, motor spirit from shale-oil and low temperature coal tar, and alcohol from vegetal sources. Eventually these sources must be extensively developed if automotive transportation is to continue to depend upon the present type of internal combustion engine for power.

Kerosene, once the mainstay of the oil refining industry, has dropped to a relatively subordinate position, and a decline in output has already set in. With the greater and greater application of electricity to lighting purposes, even in communities of relatively small size, as the network of transmission lines is extended over the country the demand for kerosene for illuminating purposes will still further decline.

Once the decline in output of crude oil is well underway and the supply of kerosene is still further encroached upon by the demand for motor-fuel, substitutes may have to be sought even for lighting purposes for farms and isolated rural communities. Illuminating oils can be obtained from shale-oils and low-temperature tars. Certain animal fats were used for illuminating purposes prior to the development of the modern petroleum industry and these could be resorted to again to help out the situation. Small acetylene gas installations offer another substitute.

The present use of enormous quantities of oil as a substitute for coal for firing under boilers to generate steam is an economic waste that will have to cease as the supply of crude diminishes. As the demand for motor and lubricating oils increases, less and less fuel oil will be turned out by the refineries. Topping and skimming plants will become a thing of the past, and a larger and larger percentage of the crude will be converted into the more essential and valuable products.

The many industrial plants and even the railroads that are now using fuel oil will have to go back to coal or else resort to hydro-electric power, in which field the future offers great possibilities. In the case of the merchant marine the conditions are somewhat different. The advantages of fuel oil over coal are so great that the nations which have an adequate supply will be placed in a distinctly superior position. Here, however, the tendency will be eventually not to burn the oil under the boilers to generate steam but to install internal combustion engines of the Diesel type and thus increase the efficiency of the fuel from two and one-half to three times.

At present considerable quantities of high grade fuel oil, known as gas oil, are employed in the manufacture of "city gas" to enrich artificial gas of low heating value, such as blue water gas. Through the withdrawal of considerable percentages of gas oil for cracking purposes a shortage has already been experienced during normal times. This will become more and more accentuated as the supply of crude diminshes, thereby forcing the gas industry to use lower grades of fuel oil and eventually to abandon its use altogether, either through change of manufacturing equipment or by making a lower grade of gas.

For running the world's machinery, a supply of lubricants will always be needed. At the present time these are derived almost entirely from petroleum products. Thus far the demand has not been sufficiently great to necessitate the recovery of these valuable oils from all of the crude run to the stills, but the time will soon come when it will be necessary to do so. The demand for lubricants, particularly the heavier bodied type, is mounting rapidly with the expansion of automotive transportation and the continued growth of industries.

Lubricating oils can be made from shale-oil and oils derived from the low-temperature carbonization of coal, as well as from certain carefully refined vegetable and animal oils and fats. These will answer for certain types of lubrication but it still remains to be proven whether they can be substituted for petroleum oils for lubricating high-speed bearings and for lubrication in the presence of high temperature and of steam.

Substitutes for most of the by-products at present arising out of the petroleum refining industry will undoubtedly be found in connection with the development of an oil-shale industry and the further extension of coal carbonization, particularly with the introduction of low-temperature processes.

CHAPTER II.

SUBSTITUTES FOR PETROLEUM PRODUCTS.

Oils and tars, from which substitutes for many of the present day petroleum products can be derived, are formed when bituminous or other varieties of coal, as well as shales rich in plant debris, are subjected to destructive distillation or carbonization in closed air tight retorts. The quantity and character of the oils and tars formed depends upon the nature of the raw material used and the method of carbonization employed.

Oils and Tars from the Carbonization of Bituminous Coal.

The yield and composition of the tar from a bituminous coal subjected to a relatively high temperature; i. e., 900 to 1200° C. rapidly applied, is different from that obtained from the same coal when the temperature does not exceed 600° C. In discussing these oils and tars, therefore, a distinction must be made between those obtained by low temperature carbonization and high temperature carbonization.

High Temperature Carbonization Oils and Tars from Bituminous Coal.

High temperature destructive distillation, during which the coal is heated to temperatures ranging from 900 to 1200° C. as quickly as possible, is the type of carbonization employed in the coal gas industry, where a large volume of gas is the primary object sought, and in the by-product coke industry, where metallurgical coke is the important product. In both industries considerable quantities of light oils and tars, as well as other valuable by-products, are obtained from the coal.

In 1918 the by-product coke ovens of the United States produced 87,222,450 gallons of crude light oil[1] and the coal gas plants, 5,914,000 gallons[2], a total of 93,136,450 gallons. The production of tar by the by-product ovens amounted to 263,299,470 gallons[1] and that of the coal gas plants to 52,694,826[2], a total of 315,994,296 gallons.

The gases and vapors produced by the high temperature distillation of coal are extremely complex in composition. Their constituents may be divided into easily condensable and difficultly condensable substances. Most of the substances of the first group are recovered by the usual operations of condensation and treatment with water or acid in the form of tar and ammoniacal liquor. There are certain substances of relatively high vapor tension such as benzene and toluene, however, which to a large extent remain uncondensed in the permanent gases. Sperr[3] estimates that only five per cent of the total benzol content in the gas is removed with the tar in the condensing plant. Only a negligible percentage of these substances have boiling points higher than that of naphthalene (218° C.).

In order to separate the light oils from the gas, the latter is first cooled by passing through a direct contact type water cooler which also removes a large portion of the napthalene content. It then goes to a scrubber where it is treated with wash or absorbent oil. In the United States the absorbent oil employed is a petroleum product, usually known as straw oil, of which at least 90 per cent should distill between 250 and 350° C. It has a specific gravity of less than .88 at 15° C. and is readily fluid at 4° C. Such an oil is capable of dissolving between two and three per cent of its volume of light oil. In European practice, heavy tar oils, 90 per cent of whose volume distills between 200 and 300° C. and which contain less than seven per cent naphthalene, are used almost exclusively for the same purpose.

Sperr gives the average composition of coke oven light oil and the yield per ton of 2,000 pounds as follows:[4]

	Per cent in light oil	Gallons per ton of coal
Benzene	66	1.782
Toluene	15	0.405
Xylene	8	0.216
Other substances principally hydrocarbons	11	0.297
		2.700

According to the same author, 1000 gallons of typical crude light oil will yield the following products:

	Gallons.
Crude benzol	680
Crude toluol	140
Crude xylol	50
Solvent naphtha	55
Wash oil residue with naphthalene	75

Products derived from the light oils obtained through the high temperature carbonization of coal are utilized for a great many different purposes. Considerable quantities are employed in the manufacture of paints, stains, varnishes, and lacquers; in the cleaning industry; in the extraction of greases and fats; as solvents for rubber; and in the manufacture of leather and insulating materials. Aniline dyes are produced from benzol. It is also the basis for the production of artificial perfumes, synthetic phenol, and the preparation of pharmaceutic compounds. Another very important industrial purpose is served by benzol and its homologues in the production of explosives, such as nitro-benzol and trinitro-toluol.

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[1] U. S. Geol. Survey, Mineral Resources, 1918, Part II, p. 1519, 1921.

[2] U. S. Geol. Survey, Mineral Resources, 1918, Part II, p. 461, 1921.

[3] Sperr, Jr., F. W. The recovery of benzol from gas, Met. and Chem. Eng., vol. XVI, pp. 135-140, 1917.

[4] Sperr, Jr., op. cit. pp. 136-139.

The lower boiling fractions of the crude light oil, namely, the benzene, toluene, and xylene, after purification make a very satisfactory motor fuel when properly used. In Europe, benzol has been extensively employed as a motor fuel but it is harder to start the engine and carbon deposition in the cylinders is greater than with gasoline.[1] Another disadvantage is that benzene solidifies at 5.4° C. or 41.7° F. The toluene and xylene present in the light oil lower this somewhat and it is still further reduced by blending with gasoline. On the other hand, benzene motor fuels are superior to gasoline in certain respects. Sperr[2] cites a certified dynamometer test by the Automobile Club of America in which 90 per cent benzene showed 12.3 per cent less fuel consumption than gasoline. At the same time the horsepower was increased, depending on the speed. At 2000 r. p. m. this was 19.4 per cent greater than that of gasoline. The higher ignition point of benzene also eliminates knocking (pre-ignition). In the United States motor benzene is blended with gasoline in order to overcome the difficulty of ignition. Such blends give a mileage about equal to gasoline and they give operation that is very smooth and free from fuel knock.

Benzol motor fuels can never be expected to satisfy more than a relatively small percentage of the total demands for automotive transportation in the United States, although in the immediate vicinity of extensive by-product coking plants they will undoubtedly become of considerable local importance. In 1918 only 93,136,450 gallons of light oil, were produced in the United States while the total gasoline production was 3,570,312,963 gallons. If all of the light oil had been available for motor fuel, only 2.6 per cent of the actual needs would have been satisfied. That year 46 per cent of the coal coked was treated in by-product ovens. If all of the coke had been produced in such ovens and the light oil recovered and made available for motor fuel, this percentage could have been increased to 5.7. The average yield per net ton of coal charged in by-product ovens in 1918 was 2.4 gallons.[3] If all of the 579,385,820 tons of bituminous coal mined that year had been treated in by-product ovens, the total light oil production would have amounted to only 1,390,526,000 gallons or less than 40 per cent of the total gasoline production.

Crude coal tar derived from the by-product coke and coal gas industries where high temperature carbonization is employed is a complex substance composed chiefly of hydrocarbons of the aromatic type and certain of their oxygen derivatives together with minor amounts of nitrogen and sulphur compounds. Weiss[4] gives the following analyses as representative of typical dehydrated high temperature tars.

Analyses of dehydrated high temperature tars.

	Gas-works coal tar			By-product coke oven coal tars		
	Horizontal retorts	Inclined retorts	Vertical retorts	United Otto	Semet—Solvay	Koppers
Specific gravity at 15.5° C.	1.266	1.238	1.153	1.207	1.188	1.186
Free carbon (per cent insoluble in benzene)	28.9	24.3	----------	13.3	10.7	6.8
Oil to soft pitch (60° C. melting point) per cent by volume	13.2	14.3	28.8	21.2	21.8	35.3
Tar acids (per cent taken on above oils)	14.0	21.0	29.0	12.0	4.0	0.0
Pitch residue (60° C. melting point) per cent by volume	86.8	85.7	71.2	78.8	78.2	64.7

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[1] McKee, Ralph H., Gasoline from oil shale. Chemical Age. New York, January, 1922, pp. 1-4.

[2] Sperr, Jr. F. W., Jour. of Ind. and Eng. Chem., vol. 13, p. 28, 1921.

[3] U. S. Geol. Survey, Mineral Resources, 1918, Part II, p. 1518, 1921.

[4] Weiss, J. M., Coal-tar pitch. Jour. of Ind. and Eng. Chem., vol. 8, p. 842, 1916.

The table below contains analyses of representatives tars made by Morgan and Soule.[1]

Analyses of representative tars.

	Low-temperature tar ("Carbo-coal" process)	Coke-oven tar (Koppers) 850-900° C. (from mixed coal 30% V. M.)	Gas-works tar 1000° C. (½ inclined & ½ horizontal retorts)
Specific gravity 15.5° C. / 15.5° C.	1.0676	1.1845	1.2172
"Free carbon" per cent	0.71	6.93	20.1
Fractions		(Percentage of total weight)	
Boiling point range, deg. C			
20-173	0.64	0.70	1.19
173-237	9.19	8.27	9.22
237-281	12.50	12.44	10.12
281-315	6.94	6.21	3.78
315-326	2.90	2.53	1.93
Pitch by difference	67.83	69.85	73.76
Air melting point of pitch deg. C	53.	69.	89.
Specific gravity of pitch 15.5° C. / 15.5° C.	1.134	1.263	1.312
"Free carbon" per cent	2.17	16.8	31.1

The yield of tar obtained by by-product coking varies with the kind of coal used and the efficiency with which the plant is operated. It may be as low as 4 or as high as 12 gallons per ton. In 1918, the average yield per net ton of coal charged in by-product ovens was 7.1 gallons.[2]

During the last few years the use of tar for fuel in the manufacture of steel has rapidly increased, due to the fact that many of the larger steel companies operate their own by-product coke plants which are usually located near the steel works. It has been found that in open hearth practice, the consumption of tar per ton of steel is 10 per cent less than the consumption of fuel oil.[3] It is advantageously employed in combination with producer gas.

High temperature coal tar is the source of a great many of the organic compounds of the chemical and allied industries, among which are some that may be employed as substitutes for certain petroleum products.

The first step in the separation of these various compounds consists in subjecting the crude tar to fractional distillation. The following fractions are usually separated.[4]

1. From atmospheric temperature to 170° C. (338° F.). Products:—light oil, water, a small quantity of pyridine, and some naphthalene.

2. From 170 to 235° C. (388 to 445° F.).
Products:—crude oil phenol, cresylic acid, crude naphthalene, pyridine, and creosote oil.

3. From 235 to 270° C. (455 to 518° F.).
Products:—creosote oil ond crude naphthalene.

4. From 270 to 315° C. (518 to 599° F.).
Products:— creosote oil ond crude anthracene.

5. From 315 to 335° C. and above (599 to 671° F.). Products:—creosote oil and crude anthracene.

Residue is pitch.

The crude naphthalene and anthracene, the latter mixed with carbazole, phenanthrene, and a larger number of less important hydrocarbons, separate out as solids from their respective fractions on cooling. The oils may then be drained off and the solids centrifuged or pressed to remove adhering oil.

Huff gives the following distillation record for a typical tar from a by-product oven:—

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[1] Morgan, Jerome P. and Soule, Roland P., Studies in the carbonization of low-temperature tar. Chem. and Met. Eng. vol. 26, pp. 923-928, 1922.

[2] U. S. Geol. Survey, Mineral Resources, 1918, Part II, p. 1518, 1921.

[3] Sperr, Jr., F. W., By-product coking. Jour. of Ind. and Eng. Chem. vol. 13, p. 28, 1921.

[4] Huff, Wilbert J., The distillation of coke-oven tar and the recovery of some of its products. Chem. and Met. Eng. vol. 26, pp. 113-118, 1922.

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Temperature (° C.)	Gallons per 1000 gallons	Per cent by volume referred to original tar volume
Atmosphere to 170	Light oil 14.5	1.45
	Ammoniacal liquor 15.5	1.55
170-235	122	12.2
235-270	123	12.3
270-315	133	13.3
315-355	98	9.8
Residue and losses	494	49.4

Weight of residue equals 57 per cent of original tar.

The following products may be obtained from such tar:—

	Gallons per 1000 gallons of tar	Per cent by volume
Ammoniacal liquor	15.5	
Light oil	14.5	1.5
Tar acids	26.0	2.6

	Pounds per 1000 gallons of tar	Per cent by weight
Crude naphthalene		
170 to 235° C. fraction	200	2.2
235 to 270° C. "	48	.6

Crude anthracene

	a	b	a	b
270 to 315° C. fraction,	46.5	9.4	0.47	0.095
315 to 355° C. fraction,	93.0	9.4	0.95	0.095
	139.5	18.8	1.42	0.190

a. Without chilling.
b. Additional recovery due to chilling.

The light oil obtained form the tar is similar in composition to that recovered from the gas by washing with absorbent oil and can, therefore, be used for the same purposes.

The tar acids are capable of forming water-soluble compounds when treated with caustic soda solutions. While present to some extent in all the fractions, they are at the highest concentration in the fraction from 170 to 235° C. Phenols and cresols are the chief compounds present. They possess important antiseptic and germicidal properties and are, therefore, extensively used in the manufacture of disinfectants. They are also the basis for the manufacture of the synthetic phenol-formaldehyde resins which resemble hard rubber and have an enormous variety of uses in the industrial world. Cresols also play an important part in the manufacture of certain coal tar colors.

A group of basic compounds known as tar bases are also present in small amounts in the tar oils. Among these, pyridine and its derivatives is the most important. It is extracted by washing with diluted sulphuric acid. Commercial pyridine generally contains a little water and higher boiling bases. The more volatile fractions, those distilling off at 115 to 160° C., are used in denaturing alcohol on account of the nauseating taste and odor that they impart. The higher fractions are used as solvents in purifying anthracene.

The residual oil remaining after the naphthalene and anthracene have been crystallized from the tar oils and the tar acids and bases have been extracted, is known as creosote oil. It is extensively used for the preservation of wood and also makes an ideal fuel for Diesel engines. A portion of the heavy tar-oil from which the crude anthracene is separated is used in the manufacture of anthracene lubricating greases.

Naphthalene is the starting point for the manufacture of a great number of coal tar dyes. A turpentine substitute is also made from it. Many other uses are being found for it, among which is the possibility of employing it as a fuel for driving internal combustion engines.

Ellis and Meigs[1] cite a trial carried out in Paris with a two cylinder Renault cab fitted with a special carburetor consisting of a melting receptacle in which the supply of melted naphthalene is maintained by the exhaust at a heat above the melting point and from which it is conveyed to a heated float feed carburetor. The engine has, in the first instance, to be started on gasoline in order to heat up the naphthalene. The time occupied in running on gasoline before naphthalene could be switched on was 13 minutes, 37 seconds. A stop of 10 minutes could be made without any further use of gasoline, while a stop of 16 minutes necessitated its use. The consumption worked out at 14.228 kilograms per 160 kilometers, at an average speed of 34.4 kilometers per hour. This is equivalent to about one-half pound per mile. In another test, conducted by the Automobile Club of France, a car, when running on naphthalene, showed an economy of 60 per cent over gasoline.

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[1] Ellis, Carleton and Meigs, Joseph V., Gasoline and other motor fuels: New York, p. 10. 1921.

Naphthalene has a comparatively high volatility and a sufficient degree of calorific power. Some of its defects, such as its high melting point, may be obviated by using it with benzine, benzol, gasoline, etc. Such mixtures are said to work very well in carburetors.

Tetralin, a hydrogenation product of naphthalene, was used during the latter period of the war in Germany as a component of motor fuel and as illuminating oil in substitution for kerosene[1] The Benzine Syndicate of Germany has recently introduced a new fuel composed of 50 per cent benzol, 25 per cent tetralin and 25 per cent of 95 per cent alcohol, which is called tetralit-benzol. It has been found suitable and acceptable. Tetralin and decalin, both hydro-napthalenes, have the following properties:—

	Tetralin	Decalin
Boiling point	205-207° C	185-187° C.
Specific gravity	.97-.98	.89-.90
Flash point	78° C.	60° C.

The potential supply of naphthalene available for motor fuel in the United States, however, is too small to have much weight as a substitute for gasoline when the supply of the latter will begin to approach exhaustion. 16,786,527 pounds of naphthalene were marketed in the United States in 1918 by the by-product coke and coal and water gas industries[2].

The crude anthracene, besides anthracene, contains carbazole and phenanthrene together with a large number of less important hydrocarbons. It is utilized in the manufacture of dyestuffs.

The pitch obtained in the distillation of high temperature tars usually constitutes from 50 to 60 per cent by weight of the original tar. Three grades: namely, soft, medium, and hard, may be produced. Coal tar pitch is used for roofing, paving, paints and protective coatings, core compounds for casting, briquet binders, pipe dip, insulating medium for electrical purposes, etc. Pitch coke made from hard pitch is a source of carbon for the electro-chemical industries

In England[3] experiments have been conducted on the manufacture of alcohol from the ethylene present in coke-oven gas. Ernest Bury has developed a process by which the ethylene in the gas is absorbed in sulphuric acid, forming ethyl sulphuric acid, which is then hydrolized to ethyl alcohol. It was found that an average yield of 1.6 gallons of alcohol could be obtained per ton of coal carbonized. Alcohol produced in this manner may become available as fuel for internal combustion engines.

Low Temperature Carbonization Oils and Tars from Bituminous Coal.

Unlike high temperature carbonization, the technical application of low temperature carbonization of bituminous coal on a commercial scale is still in its infancy, although an enormous amount of experimental work, chiefly on a laboratory or at the best only on a semi-commercial scale, has been done during the last twenty years. Davis[4] has summarized the main reasons why progress toward commercial development has been slow, as follows:—"(1) adequate fundamental knowledge of coal constitution and thermal decomposition is lacking; (2) evolution of suitable retorting apparatus is slow owing to the low heat conductivity of coal and the consequent difficulty of designing retorts of appreciable capacity, having at the same time the requisite low temperature gradients; (3) a market for the

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1. Furness, R. S., The hydrogenation of naphthalene: Chemical Age, New York, vol. 30, pp. 173-176, 1922.
2. U. S. Geol. Survey, Mineral Resources, 1918, Part II, p. 1523, 1921.
3. Chem. and Met. Eng., vol. 22, p. 487, 1920.
4. Davis, Joseph E., Present status of coal carbonization at low temperature, Report of the Carbonization Committee, American Gas Association, p. 18, 1921.

rather special distillation products, however valuable they may prove to be in the future, does not exist and must be created."

The oils and tars obtained from the low temperature carbonization of coal are considerably greater in volume and are of different composition than those obtained by high temperature processes. They are often spoken of as primary tars because ordinary coal tar is formed from them through decomposition, brought about by the higher temperatures to which the gases and vapors are subjected in the ordinary coke oven or gas retort. On the other hand, the fact must not be lost sight of that even the ordinary low temperature tar prepared on a commercial scale has already undergone a limited amount of decomposition, due to secondary reactions that have had an opportunity to take place in the retort, as compared with vacuum tars prepared on a small scale in the chemical laboratory. As Morgan and Soule[1] have pointed out, the low heat conductivity of coal makes the exact nature of tars distilled at approximately the same temperature dependent upon such factors as agitation, rate of distillation, the thickness of the fuel layer, and the resulting temperature gradient. Also, the pressure developed inside the retort, the use of steam, the size of the gas space, the temperature of the crown of the retort and other conditions controlling the escape of the gases are factors which have an important influence on the extent to which secondary reactions are developed.

There is still some difference of opinion among investigators as to what temperatures are most desirable for this type of carbonization. Parr[2] believes that the upper limit to which low temperature carbonization can be carried is 750 to 800° C. Above these temperatures the low temperature tars commence to undergo decomposition with the formation of compounds characteristic of ordinary coal tars. Bone[3] considers temperatures of from 450 to 550° C. as the most desirable. Gluud[4] defines low temperature carbonization as that conducted between 500 and 600° C. Both Parr and Gluud agree that at temperatures of 800 degrees and above the low temperature tars begin to undergo appreciable decomposition.

Low temperature tars, as compared to high temperature tars, are thin and light, having a consistency much more resembling mineral oils. Their specific gravities very closely approximate unity so that the separation of water from them is at times difficult. They contain practically no free carbon. Morgan and Soule[5] found that a commercial low-temperature tar produced by the primary retorts of the "Carbocoal" process from Pittsburgh coal yields 32.17 per cent by weight of distillate below 326° C. and atmospheric pressure, which consists chiefly of phenols (42.7 per cent by weight), cyclic unsaturated hydrocarbons (41.5 per cent), naphthene hydrocarbons (8.8 per cent), paraffin hydrocarbons (5.1 per cent), and nitrogen bases (1.9 per cent), Jones and Wheeler[6] have examined coal tars obtained by distillation in vacuo below 450° C. A yield of approximately 6.5 per cent of the weight of the coal, equivalent to about 16 gallons per ton was obtained. The tars ranged in specific gravity from 0.967 to 0.999 at 15° C. It was found that about one-half of this tar distilled below 300° C. at ordinary pressures. The distillate yielded unsaturated hydrocarbons (40 to 45 per cent); naphthenes; liquid paraffins (the two last named being about 40 per cent of the oil, with naphthenes predominating); phenols, chiefly cresols and xylenols (12 to 15 per cent); aromatic compounds, which on account of the stability of their picrates to water, were considered to be homologues of naphthalene; pyridine bases in traces; and traces of the solid paraffin, $C_{27}H_{56}$. Benzine and its homologues were absent, as were also naphthalene, anthracene, phenanthrene, and solid aromatic bodies generally.

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[1] Morgan, Jerome J., and Soule, Roland P., Characteristics of low-temperature tar. Chem. and Met. Eng., Vol. 26, pp. 923-928, 1922.

[2] Parr, S. W. and Layng, T. E., Low temperature carbonization and its application to high oxygen coals. Jour. of Ind. and Eng. Chem., Vol. 13, p. 14, 1921.

[3] Bone, William S., Coal and its scientific uses, p. 133, London, 1919.

[4] Gluud, W., Die Tieftemperaturverkokung der Steinkohle, 2nd edition, p. 13, 1921.

[5] Morgan Jerome J. and Soule, Roland P. op. cit. pp. 923-928.

[6] Jones, David Trevor. The thermal decomposition of low-temperature coal tar, Jour. Soc. Chem. Ind. Vol. 36, pp. 3-7, 1917.

The yield of tar and oil from bituminous coal, obtained through low temperature carbonization, depends upon the composition of the coal and also to a certain extent upon the conditions to which the coal is subjected during distillation. In general, it may be said that the volume of tar is from two to three times that obtained when the same coal is treated in the ordinary coke oven or gas retort at high temperatures. From an ordinary bituminous coal with proper treatment, as a rule 20 to 30 gallons of low-temperature tar can be obtained per ton. German gas coals, according to Gluud[1], yield from 8 to 12 per cent by weight of such tar. This is equivalent to approximately 19 to 29 gallons per ton. Curtis[2] states that a bituminous coal, containing 35 per cent volatile matter, 58 per cent fixed carbon, and 7 per cent ash, yields 24 gallons of tar per ton when treated in the low-temperature retorts of the "Carbocoal" process. In addition, 1½ gallons of light oil are recovered from the gas. Parr and Olin[3] have made a rather detailed examination of a low-temperature tar (400-500° C.), obtained from a Vermilion County, Illinois bituminous coal, which had the following composition:—

	per cent.
Moisture	8.80
Volatile matter	43.05
Fixed carbon	39.43
Ash	8.72
Sulphur	2.88

It yielded approximately 8 per cent by weight of tar or 18 gallons per ton. The tar had a specific gravity of 1.069 at 20° C. and a free carbon content of 1.35 per cent.

The tar was first dehydrated and then subjected to a preliminary distillation by which it was divided into the following fractions:—

Light oil	below 210 C.	17.2 per cent.
Heavy oil	210 to 325 C.	52.7 " "
Pitch	above 325 C.	30.1 " "

The light oil fraction had a specific gravity of .966 and contained the following constituents:—

	Percentage on basis of crude tar		Percentage on basis of light oil fraction.
Light oil fraction	17.2		100.0
Phenols (and other acid substances)	5.7		33.0
Amines (and other bases)	0.9		5.3
Paraffins	3.12	10.6	18.1
Other neutral oils (by difference)	7.48		43.6

Distribution of neutral substances in light oil.

Fraction (in °C.)	Percentage on basis of crude tar.
20 to 75	.25
75 to 95	.38
95 to 125	1.33
125 to 170	4.77
170 to 200	2.67
200 to 210	1.32
	10.72

The heavy oil fraction had a specific gravity of 1.032 and possessed the following composition:—

	Percentage on basis of crude tar.	Percentage on basis of heavy oil fraction.
Heavy oil fraction	52.7	100.0
Tar acids	22.2	42.13

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[1] Gluud, W. op. cit. p. 57.

[2] Curtis, Harry A., Low-temperature carbonization of coal and manufacture of smokeless fuel briquets. Chem. and Met. Eng., Vol. 23, p. 500, 1920.

[3] Parr, S. W. and Olin, H. L., The coking of coal at low temperatures with special reference to the properties and composition of the products: University of Illinois Engineering Experiment Station, Bull. 79, pp. 20-26, 1915.

Paraffins	6.2	30.5	11.76
Naphthalene	0.0		0.0
Anthracene	0.0		0.0
Other neutral oils and bases by difference	24.3		46.11

Distillation of the acid free portion of the heavy oil fraction gave the following results:—

Fraction	Percentage on basis of crude tar.
210 to 250 degrees C.	2.87
250 to 270 " "	13.55
270 to pitch	11.53
	27.95

The pitch obtained from the preliminary distillation had a melting point of 110° C., a specific gravity of 1.27 and a free carbon content of 12 per cent.

A low-temperature tar, produced by the primary retorts of the "Carbocoal" process from Pittsburgh coal, has been made the subject of a detailed investigation by Morgan and Soule.[1]

The coal had the following composition computed on a dry basis:—volatile matter, 35.30 per cent; fixed carbon, 57.92; ash, 6.78; nitrogen, 1.65 and sulphur 1.77 per cent. It yielded 11.3 per cent by weight of crude dry tar, having a specific gravity of 1.0676 at 15.5° C. This is equivalent to 25.4 gallons per ton. The tar had a free carbon content of .71 per cent.

A dry distillation at atmospheric pressure of the dehydrated tar gave the following results:

Fraction Boiling point range Degrees C. (corrected for emergent stem)	Percentage of total weight	
20-173	0.64	32.17
173-237	9.19	
237-281	12.50	
281-315	6.94	
315-326	2.90	
Pitch (by difference)		67.83
		100.00

The distillate had the following composition:—

	Per cent by weight of distillate.	Per cent by weight of crude tar.
Phenols	42.7	13.7
Bases	1.94	0.624
Alcohols	0.0	0.0
Hydrocarbons		
Paraffin	5.1	1.6
Naphthene	8.8	2.8
Unsaturated (cyclic)	41.5	13.4
Aromatic	....	....
	100.04	32.124

The composition of the phenols was found to be as follows:—

	Percentage by weight
Phenol	4.2
Cresols	33.4
Xylenol fraction	19.0
Higher homologues	34.8
Pitch (acid resins)	8.6
	100.0

The cresols consisted of 27 per cent ortho-, 19 per cent meta-, and 54 per cent para-cresols.

The bases contained no primary, about 20 per cent secondary, and 80 per cent of tertiary bases.

The pitch obtained from the low-temperature tar by cutting at 326° C. had a specific gravity of 1.134 at 15.5° C., a free carbon content of 2.17 per cent, and an air melting point of 53° C.

Gluud[2] recommends that the tars be refined by distillation with superheated steam. He obtained the following products from low-temperature tar from gas coal:—

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[1] Morgan, Jerome J. and Soule, Roland P., op. cit. pp. 923-928 and 977-981.
[2] Gluud, W., Die Tieftemperaturverkokung der Steinkohle, 2nd edition, Halle, p. 84, 1921.

Boiling range	Yield % of tar	Product
20-100° C.	3.0	Paraffin from the gas.
100-200° C.	10.0	Light oil.
200-300° C.	12.5	Low viscosity oil; solar oil; motor oil; polishing oil, containing 1 per cent of fluid paraffin oil
300° to dry point	15.0	Lubricating oil (V50 2-30 deg. E.), containing 1½ per cent solid paraffin.
	9.0	Red resin.

In addition to the above products, 50 per cent of the tar was obtained as phenolic compounds, boiling above 200° C..

The light oils, obtained from low-temperature tars after proper refining, make excellent motor fuel and will undoubtedly find a ready market for this purpose as soon as low-temperature carbonization is developed on a commercial scale. Illuminating oils can be made from the middle fractions and these, as well as the heavy oils when used in combination with them, can be employed as fuel for internal combustion engines of the Diesel type. Good lubricants can be made from the heavier fractions by steam distilling and removing the phenols.

The tar acids or phenols which are present in large quantities in low-temperature tars have a variety of uses. They are suitable for use as insectides, including dip oil for livestock, and for flotation oils. In the future, they will probably also be extensively employed in connection with timber preservation. At present, the greatest demand is for the manufacture of disinfectants.

Undoubtedly, the pitch obtained in the distillation and refining of low-temperature tars will be found to be suitable for many of the same purposes for which pitch from coke-oven and gas-work tars is now employed. In the "Carbocoal" process, which is essentially a low-temperature one, the pitch is employed in making briquets from the carbonized coal.

According to Gluud,[1] the crude tars, without refining, were extensively used in Germany as lubricants during the war and are still used for that purpose to a certain extent at the present time where a low-grade oil will answer. The crude oil can also be employed as fuel oil with little or no refining, but it will undoubtedly prove to be so much more valuable for other purposes as to preclude such use. According to Brownlie[2], the whole fraction up to 300° C. of a low-temperature tar produced by the "coalite" process, has been successfully used in a cold-starting Ruston and Hornsby oil engine, and resulted in a consumption of .49 pounds per brake horse-power at the most economical load.

Oils and Tars from Cannel Coal and Shale.

Cannel coal differs from ordinary coal in that it contains a higher percentage of volatile matter, as compared with fixed carbon, than the latter. This holds true in most instances for those cannel coals which occur associated with ordinary coal of bituminous, sub-bituminous, and lignitic rank; but in the case of cannels which approach or have reached semi-bituminous rank, so much volatile matter has been lost through metamorphism that such a distinction can no longer be made. The organic matter of cannel coals consists largely of plant spores and pollen grains, together with more or less comminuted remains of low order of water plants, probably in some instances including algae, and plants free from woody tissues. Woody portions of plants, still showing cell structure, which are so prominent in ordinary coal, are present only in small quantity or may be entirely absent. As a rule, cannel coals have a high ash content and frequently grade into cannel shale on this account.

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[1] Gluud, W., op. cit., p. 67.

[2] Brownlie, David, The manufacture of smokeless fuel, Engineering, London, Vol. CXII, p. 601, 1921.

In general, larger quantities of oil can be obtained through low-temperature carbonization from cannel than from ordinary bituminous coal. Exceptionally high grade cannel coals will yield 55 or even more gallons of water-free oil per ton, and many are capable of producing 42 gallons, or one barrel. Low grade cannel shales may only give 20 to 25 gallons. The quantity and character of the oil depends upon the nature of the organic matter present in the coal or shale, the amount of alteration and metamorphism which it has undergone, the percentage of inorganic material or ash present, and finally, the conditions under which carbonization is conducted.

Cannel coal oils have lower specific gravities than low-temperature tars from bituminous coal—the former ranging from .88 to .95, while the latter are usually very nearly 1.00. They can, therefore, be more readily freed from their water content. The percentage of tar acids present in them is usually considerably smaller than that in the low-temperature tars from bituminous coal; in some instances, amounting to only 4 to 8 per cent of the total volume of the oil, as compared with 25 to 50 per cent in the latter.

Dunlap[1] has examined oils obtained from Missouri cannel coals by low-temperature carbonization. His results with cannel coal from Bunceton, Cooper County and cannel shale from the Ouachita mine in Morgan County are perhaps most typical of what can be expected from materials of this character in general. The proximate analyses of the Bunceton cannel coal and the Ouachita cannel shale showed the following composition:—

	Bunceton cannel coal	Ouachita cannel shale
Moisture	.82	4.90
Volatile matter	51.42	25.49
Fixed carbon	39.60	14.55
Ash	8.16	55.06
	100.00	100.00

Two carbonization runs on the Bunceton coal gave 53.5 gallons of oil plus 5.09 gallons of water, and 48.32 gallons of oil plus 7.00 gallons of water, respectively, while two similar runs on the Ouachita cannel shale yielded 27.79 gallons of oil plus 24.09 gallons of water, and 25.13 gallons of oil plus 24.49 gallons of water.

Analyses of general samples of the oils brought out the following characteristics:—

	Bunceton cannel oil	Ouachita cannel oil
Specific gravity	.9152	.9081
Water, per cent	6.00	11.30
Flashing point, °F.	110.0	90.0
Burning point, °F.	200.0	105.0
Viscosity, 60 °C.	1.16	1.48
Tar acid, per cent	6.80	8.33
Tar base, per cent	1.00	0.00
Volatile matter, per cent,	91.81	99.30
Ash, per cent	.16	.03
Fixed carbon, per cent	2.02	1.67
Free carbon, per cent	7.04	.87
Naphthalene, per cent	none	none
Limpid point, °C.	1.5	4.0
Unsulphonated residue, per cent	15.00	80.16

Fractional distillation tests gave the following results:

	Bunceton cannel oil (per cent)	Ouachita cannel oil (per cent)
Water	6.6	11.3
Distilling up to 170° C.	14.0	8.3
170 to 235° C.	17.2	22.9
235 to 270° C.	13.4	12.6
270 to 355° C.	38.8	40.4
Pitch	10.0	4.5
	100.0	100.0

Berry and Dunston in a report on the cannel coal deposits of Great Britain as a possible source of oil give the following results obtained from various tests on two samples of cannel oil.[2]

Boghead cannel oil

	Per cent	
Specific gravity	0.916	
Water	0.5	
Distilling up to 170° C.	8.0	
170 to 230° C.	10.0	
230 to 270° C.	13.0	Sp. Gr. =0.832
270 to 350° C.	38.0	Sp. Gr. =0.886
Pitch	30.5	
	100.0	

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[1] Dunlap, Howard Leroy. The carbonization of Missouri cannel coals. Bull. Missouri School of Mines, Vol. 5, No. 1, August, 1919.

[2] Berry, A. G. V. and Dunston, A. E., A new British oil industry, Part III, Journal of the Institution of Petroleum Technologists, Vol. 4, p. 132, April, 1918.

Tar acids averaged 9 per cent. of the total distillate.

Another cannel oil

	Per cent
Specific gravity	0.940
Water	7.0
Distilling up to 170° C.	6.5
170 to 230° C.	8.0
230 to 270° C.	9.5
270 to 330° C.	27.0
	58.0

Tar acids averaged 7 per cent. of the total distillate.

In conclusion, it may be stated that cannel coals and shales, as a rule, not only yield larger volumes of oil per ton of material treated, but that these oils are of superior quality to those derived from ordinary coal, if the object sought is the manufacture of substitutes for petroleum products. Unfortunately, cannel coals usually run so high in ash that the residue obtained after carbonization has little value as fuel. Also, cannel coal and shale deposits are rarely of sufficient extent to warrant the expenditure of any very large sums of money for the erection of plants to treat them. They will, therefore, never play a very important role as sources of oils to replace a waning petroleum supply.

Oils and Tars from Lignites.

Lignites have attracted a certain amount of attention as possible future sources of oil supply. Lignites as mined usually contain from 30 to 35 per cent of moisture and hence do not make a very desirable fuel in a raw state. Low-temperature carbonization is one means of making commercial fuels from them. When subjected to such carbonization, oils and tars are among the products driven off. The quantity, as well as the quality, of these tars depends in large part upon the nature of the vegetable debris constituting the lignite.

White and Thiessen[1] have distinguished two types of lignite, a woody or xyloid variety and a canneloid one. The former consists largely of woody material with only minor amounts of finely divided debris occurring as a filling between the interstices. In the latter the finely divided debris predominates. Woody material is practically absent. These coals on microscopic examination are found to be made up largely of resinous bodies, spores, pollen grains, macerated fragments of bark, leaves, and cellulosic debris.

Lignites, presumably the ordinary or woody variety, from southeastern Saskatchewan, Canada were carbonized at 575 to 600° C. by Stansfield[2] and found to yield from 4.2 to 6.9 imperial gallons (5 to 8.3 U. S. gallons) of tar oils per ton of 2,000 pounds when computed on the basis of a 33 per cent water and 7 per cent ash content. These oils have a specific gravity of very nearly 1.0.

Distillation results on lignite tar from the carbonization of lignites from the Estevan area, southeastern Saskatchewan at 575 to 600° C., were as follows:[3]

Source of lignite	Shand mine	Western Dominion mine	Bienfait mine
Results on dry tar basis—			
Up to 170° C.	8.2	3.8	4.7
170 to 200° C.	4.5	4.9	3.8
200 to 270° C.	28.3	23.9	23.4
270 to 310° C.	19.3	20.4	20.9
Residue	36.5	45.1	45.3
Gas and Loss	3.2	1.9	1.9
	100.0	100.0	100.0

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1. White, David and Thiessen, Reinhardt. The origin of coal, Bulletin 38, U. S. Bureau of Mines, 1913.
2. Stansfield, Edgar and Gilmore, Ross E. Lignite carbonization. Mines Branch, Department of Mines Summary Report for 1918, p. 105, Ottawa, Canada, 1920.
3. Stansfield, Edgar, Gilmore, Ross E., Nicolls, J. H.H., Hardy, T. W. and others. Lignite carbonization. Mines Branch, Department of Mines Summary Report for 1919, p. 35, Ottawa, Canada, 1920.

A canneloid lignite from the Camden field in southern Arkansas, which has been utilized to a small extent for the distillation products that can be obtained from it by carbonization, yields as high as 38 gallons of oil per ton.[1] The average oil production from the lignite as it is mined and distilled approximates 25 gallons. The distillates are said to be used in the rubber industry, in soap making, in paints, and in various proprietary preparations.

Since the middle of the last century canneloid lignites have been extensively utilized in Germany for distillation purposes on account of their relatively high oil yield. Deposits suitable for carbonization are found west of Cologne in the Rhine Province; in the neighborhood of Halle on the Saale in the Provinces of Saxony and Thuringia; and at Messel, near Darmstadt, in the Hessen Province.

In the Saxon-Thuringia industry, the average yield of the tar from the charge at the present time is about 2½ to 5 pounds per bushel of 50 to 60 pounds (equivalent to 11 to 27 gallons per ton).[2] In former years, when there was an abundance of richer material available, it was considerably higher. The lignite tars have specific gravities of from 0.850 to 0.910 determined at 44° C. (111° F.) and furnish the following products on refining.[3]

	Per cent.
Light lignite tar oil (benzine)	2 to 3
Solar oil	2 to 3
Pale vaseline oil	10 to 12
Gas oil	30 to 35
Heavy vaseline oil (yields an inferior lubricating oil)	10 to 15
Hard paraffin	8 to 12
Soft paraffin	3 to 6
By-products	4 to 6
Water, gas, and loss	20 to 25

Gluud[4] gives the following yields of refined products that are obtained from tars made from Rhine Province lignites:—

Boiling range	Yield per cent. of tar		Product
Up to 200° C.	3.4		Light oil.
200 to 300° C.	25.9		Low viscosity oil.
300 to pitch	16.5	3.1 V92 7.4° E. 9.9 V20 8.5° E. 3.5 V20 7.5° E.	Viscous oil.
	14.5		Crude paraffin.
200° C and above	27.6		Tar acids and small amounts of bases.
	2.6		Resin.
	9.5		Pitch.
	100.0		

The lignite yields 7.5 per cent of crude tar, figured on a moisture free basis (dried at 105° C.), which is equivalent to about 20 gallons per ton.

Peat Tars.

Peat carbonization plants in which tars are recovered as by-products have been operated in Bavaria, Germany, and Russia. The quantity of tar represents from 2 to 5 per cent of the dry weight of the peat used, or about 5 to 12 gallons per ton. The dry tar yields the following products:[5]

	Crude Per cent.	After purification Per cent.
Light naphtha	16	12
Heavy naphtha	30	25
Lubricating oil	15	13
Paraffin wax	12	2
Peat-tar pitch	16	16
Creosote	—	12
Loss	11	20
	100	100

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1. White, David and Thiessen, Reinhardt, op. cit., p. 18.
2. Scheithauer, W., Shale oils and tars, translated by Chas. Salter, p. 33, London, 1913.
3. Scheithauer, W., op. cit., p. 113.
4. Gluud, W., op. cit. p. 85.
5. Abraham, Herbert, Asphalts and Allied Substances, 2nd edition, pp. 200-202, New York, 1920.

The dried peat tars in general range in specific gravity from 0.90 to 1.05 at 77° F. Tars recovered from gas producers in which peat is used as a fuel are very similar to the above in composition, but the yield only amounts to 1 to 2 per cent by weight of the dry peat.

In northern New Zealand around Auckland, peat deposits occur in which are found considerable quantities of kauri-gum.[1] Kauri-gum is a resin which exudes from and collects in yellow or brown lumps at the base of the kauri tree. Kauri-gum is used in the manufacture of high-grade varnishes. The residual peat, after the lumps of resin have been removed, is carbonized with the recovery of from 40 to 50 gallons of kauri-gum oil per cubic yard. This oil is said to yield about 15 per cent of good motor fuel, 30 per cent of paint oil, 30 per cent of varnish oils, and the balance a commercial pitch.

Shale Oils.

The enormous deposits of oil shale, which occur in the United States as well as in other parts of the world, contain a great potential reserve of oil that can and undoubtedly will be drawn upon very extensively in the comparatively near future. As soon as the impending shortage of petroleum becomes sufficiently acute, the price will rise to a point where the development of an oil shale industry on a commercial scale will be possible and shale oil products will be able to compete with petroleum products. Some investigators believe that this point will be reached within the next five years. All present indications are that the extensive development of such an industry in the United States will be inaugurated within the next ten or twenty years.

Oil shales consist of argillaceous and other fine grained mineral sediments with which are very intimately associated and intermingled varying amounts of organic debris of vegetable or animal origin, in most instances chiefly the former. The organic debris on carbonization yields oils which in many respects resemble crude petroleum. In all true oil shales, the oil is derived from organic materials which were deposited with the sediments at the time that they were laid down, and is not derived from oil which has seeped in from some outside source later on. The oils that are obtained from oil shales from different localities vary considerably in composition, just as do the petroleum oils found in various parts of the world. In addition to this, the character of the carbonization process, to which the shale is subjected, also has a marked influence upon the nature and composition of the oil as well as on the yield.

Thus far the only country that has developed an extensive oil shale industry is Scotland. Shales were first resorted to in Scotland as a source of oil in 1862[2] when the supply of Torbane Hill mineral, which was a variety of cannel coal, became exhausted. To meet the keen competition which arose with the rapid expansion of the petroleum industry, the larger companies were forced to consolidate their interests and continually improve their practice, while the smaller ones went out of existence. In this way the Scotch industry has managed to survive, although it has been hard hit since the close of the World War. At present, very little shale is being mined. The various companies operating in the Scotch shale fields have united into one organization, known as Scottish Oils, limited, which has made an arrangement with the Anglo-Persian Oil Company by which the latter furnishes crude oil from Persia to operate the refineries formerly run on shale oil. This state of affairs has been brought about by the increased cost of labor, the gradual exhaustion of the richer and more readily accessible beds of shale, and the increased importation into Great Britain of crude petroleum from its foreign dominions. Whether it will again be possible to work the oil shale deposits of Scotland on an extensive scale, after the present business depression has passed, remains for the future to determine.

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[1] The Oil and Gas Journal, July 4, 1919, p. 2. Kauri-gum industry in New Zealand, Chem. and Met. Eng., Vol. 23, p. 1197, 1920.

[2] Steuart, D. R., The chemistry of the oil-shales: The oil shales of the Lothians, 2nd ed. pt. 3, p. 137, Scotland Geol. Survey Mem., 1912.

Oil Shales of Scotland.

The oil shales of Scotland occur in strata of Lower Carboniferous age. They lie below the Lower Carboniferous marine limestone of southern Scotland and above the recognized Devonian. The shale worked in recent years has been yielding approximately 10,000 cubic feet of gas having a heating value of about 240 B. t. u. per 1,000 cubic feet, approximately 24.5 U. S. gallons of crude oil, and 36 pounds of ammonium sulphate per short ton.[1]

The yield of refined products has been somewhat as follows:—

	Per cent.
Naphtha (including scrubber naphtha) 450° F. end point	9.9
Burning oils (kerosene and the like)	24.7
Gas and fuel oils	24.4
Lubricating oils	6.7
Wax	9.5
Still coke	2.0
Loss	22.8
	100.0

According to Steuart,[2] the oil shale, after being broken up by machines of special construction and subjected to destructive distillation in retorts, gives crude oil, ammonia water, and gas. The crude oil is refined by repeated distillations and treatments with chemicals, and the marketable products are:—

1. Shale spirit or naphtha, with specific gravity from .660 to .750 at 60° F. (15.5° C.). Oils too volatile for safety in domestic illumination, and used chiefly as solvents and for motor spirit.

2. Burning or lamp oils. Sp. gr. .770 to .830, the average being about .800. Used for lamp and internal combustion engines.

3. Gas or intermediate oils. Sp. gr. .840 to .865, with properties intermediate between those of the burning and lubricating oils, and used for gas making, gas enriching, fuel for the Navy, internal combustion engines, and for cleaning purposes.

4. Lubricating oils. Sp. gr. .865 to .895, of high boiling point and viscosity, used for lubricating machinery.

5. Solid paraffin. Melting points from 100° to 130° F. (38 to 54° C.). Used for candle making and other purposes.

6. Still coke, still grease, etc.

7. Still gases used for illuminating the neighboring villages.

In 1910,[3] the production was approximately as follows:—

Shale distilled	3,130,000	tons
Crude oil produced	273,000	tons or
	70,000,000	gallons

The marketable products were:—

Motor spirit	600,000	gallons
Naphtha	4,400,000	"
Burning oil	20,000,000	"
Gas fuel oils	12,000,000	"
Lubricating oils	10,000,000	"
Paraffin wax	25,000	tons
Sulphate of ammonia	54,000	"

In analyzing the above statistics it must be kept in mind that in Great Britain the long ton (2,240 pounds), is used, and the Imperial gallon, which equals 1.20095 U. S. liquid gallons. Recasting the above figures into American units, the average yield per ton of 2,000 pounds was as follows:—

Crude oil	24.0	gallons	(U.S.)
Motor spirit	.3	"	"
Naphtha	1.5	"	"
Burning oil	6.9	"	"
Gas or fuel oils	4.1	"	"
Lubricating oils	3.4	"	"
Paraffin wax	16.0	pounds	
Sulphate of ammonia	34.5	"	

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1. Gavin, Martin J. The necessity for research in the oil shale industry, Chem. and Met. Eng., Vol. 23, p. 491, 1920.
2. Steuart, D. R. op. cit. p. 136.
3. Steuart, D. R., op. cit., pp. 138-139.

Scotch retorts are built in two sections. The upper part, made of cast iron, is about 12 feet long, circular in cross-section, and has a vapor outlet near the top. Shale which has been passed through toothed rolls is fed into it at intervals from a hopper placed above the retort. In this upper portion the temperature does not exceed 900° F. (482° C.), and it is here that most of the oil is distilled off.

The lower part of the retort is circular in cross-section, about 18 feet high, and is built of special shaped fire brick. The joint between the upper and lower parts is sealed with fire clay. The whole retort tapers, having an internal diameter of about 2 feet at the top and 3 feet at the bottom. In the lower or masonry part the temperature is raised to about 1500° F. (816° C.). This portion of the retort serves mainly as an ammonia and gas producer. About 105 gallons of water in the form of exhaust steam is admitted at the bottom for each 25 gallons of oil produced. The steam serves to absorb the heat from the spent shale, to produce water gas from the fixed carbon remaining in the spent shale, to distribute evenly the heat in the retort, to produce ammonia from the nitrogen of the shale, and to carry off the oil products formed.

Distillation with steam increases the yield of ammonia about two and one-half times, as compared with dry distillation, and also produces more and better oil. The spent shale is discharged continuously from the bottom of the retort. It contains only 1½ to 2 per cent of fixed carbon.

A retort of this type will produce approximately 100 gallons of oil per day whether it is working on rich or lean materials.[1] Each retort with its supply hopper holds about nine tons of shale. The feed is by gravity. Four retorts are set in a common furnace and are heated by the combustion of the fixed gases resulting from the distillation of the shale, supplemented by coal producer gas when necessary. Sixteen of the above units constitute a bench, two retorts wide and thirty-two retorts long.

The operation of manufacturing finished products from the crude shale oil is somewhat similar to that of refining petroleum. The total crude from the retort condensers is first run to coke. The distillate is then separated into several fractions by distillation. These are treated with sulphuric acid and caustic soda solution and redistilled. In the case of some of the products, this is repeated a second time. According to Steuart,[2] the sulphuric acid used in refining combines with the pyridene bases and other basic substances, the bulk of the phenols, the sulphur compounds, and the hydrocarbons that are less saturated than olefines. The caustic soda solution extracts phenols and acids. In the finishing treatments, an effort is made to extract the last traces of the compounds more unsaturated than olefines, and also the sulphur compounds; and for this purpose sufficient acid is used to attack a little of the olefines.

Oil Shales of New Brunswick and Nova Scotia, Canada.

Rather extensive deposits of oil shale are found in New Brunswick and Nova Scotia, Canada. In New Brunswick they occur in the upper portion of the Devonian; in Nova Scotia they are found at several horizons, in part in the Upper Devonian, and also in the Upper Carboniferous or Pennsylvania strata at the base of the coal measures.[3]

In 1908, 45 to 50 tons of oil shale from the Irving seam near Baltimore, Albert County New Brunswick, which has a thickness of about six feet at this locality, were mined and shipped to the works of the Pumpherston Oil Company of Scotland for a test on a commercial scale. From 363¾ long tons of this shale 1,473 gallons of crude oil, an average of 40.09 Imperial gallons per ton, of specific gravity 0.919, were obtained. The ammonium sulphate yield was 77 pounds per ton.[1] This is equivalent to 43 U. S. gallons of crude oil and 69 pounds of ammonium sulphate per ton of 2,000 pounds.

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[1] Gavin, Martin J. The necessity for research in the oil shale industry. Chem. and Met. Eng., Vol. 23, p. 490, 1920.

[2] Steuart, D. R. op. cit. p. 189.

[3] Ells, R. W., Bituminous shales of Nova Scotia and New Brunswick. Geological Survey Branch, Department of Mines of Canada Summary Report 1908, p. 132. Ottawa, 1909.

Two methods of refining the crude oil were used.[2] In method A, the crude oil was distilled and fractionated into (1) crude naphtha and (2) crude distillate. The crude distillate was treated with sulphuric acid (1.84 sp. gr.) and caustic soda solution (1.35 sp. gr.), then again distilled and fractionated into (3) crude burning oil, (4) heavy oil, and (5) residuum. Nos. (1) and (3) were further refined by treatment with acid and soda and distillations. No. (4) was cooled to a low temperature and filter pressed to extract the solid paraffin (6). The blue oil (7) was filtered from (4), treated with acid (1.72 and 1.84 sp. gr.) and soda (1.35 sp. gr.), distilled off of solid caustic soda, and fractionated into various products; the refining of some of these being completed by a final treatment with acid and soda.

In method B, the crude oil was treated with sulphuric acid (1.22 sp. gr.), then distilled and fractionated into (1) crude naphtha, and (2) crude distillate. The crude distillate was treated with sulphuric acid (1.72 and 1.84 sp. gr.) and caustic soda solution (1.35 sp. gr.), then again distilled and fractionated into (3) crude burning oil, (4) heavy oil, and (5) residuum. No. (4), cooled and filtered, gave solid paraffin (6) and blue oil (7). No. (7) was then treated with acid (1.84 sp. gr.) and soda, distilled off of caustic soda, and fractionated into various products; the refining of some of these being completed by a final treatment with acid and soda.

Tabular statement of refined products.

Method A.

Product	Gallons per 100 gallons of crude oil	Specific gravity 60° F.	Setting point Deg. F.	Melting point Deg. F.
Heavy naphtha	1.62	0.7670		
Burning oil	10.04	0.7954		
Gas oil	14.87	0.8431	25°	
Cleaning oil	2.83	0.8713	25°	
Lubricating oil	9.58	0.8957	30°	
Crude wax	2.26			112.26°
Crude wax	0.93			101.0 °
Crude wax				
Residuum from blue oil (refined)	0.28			
Residuum from treated crude distillate refined)	1.27			
	43.68			

Total crude wax containing 4 per cent. oil=3.19 gallons=2.907 gallons refined wax, melting point 108.98° F.

Sulphuric acid used in refining 100 gallons crude oil=4.705 gallons (1.84 sp. gr.).

Method B.

Product	Gallons per 100 gallons of crude oil	Specific gravity 60° F.	Setting point Deg. F.	Melting point Deg. F.
Heavy naphtha	1.45	0.7670		
Burning oil	11.50	0.7955		
Gas oil	13.04	0.8450	25°	
Cleaning oil	1.56	0.8705	26°	
Lubricating oil	11.03	0.8935	30°	
Crude wax	2.21			111.3°
Crude wax	0.60			104.0°
Crude wax	0.16			84.0°
Residuum from blue oil (refined)	0.57			
Residuum from treated crude distillate (refined)	1.95			
	44.07			

Total crude wax containing 4 per cent. oil=2.97 gallons=2.2707 gallons refined wax, melting point 108.38° F.

Sulphuric acid used in refining 100 gallons crude oil=4.68 gallons (1.84 sp. gr.).

Flash point of burning oil: 117° F. (Abel close test). Viscosity of lubricating oil: 200 seconds at 70° F. (Redwoods' apparatus).

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[1] Ells, R. W. Joint report on the bituminous oil-shales of New Brunswick and Nova Scotia, Part II, p. 44. Geology No. 1107. Canada Dep. Mines, Ottawa, 1910.

[2] Ells, R. W. Joint report on the bituminous oil shales of New Brunswick and Nova Scotia, Part I, Economics, No. 55, pp. 13-14. Canada Dep. Mines, Ottawa, 1910.

Oil Shales of the United States.

The largest deposits of high grade oil shale in the United States and perhaps in the world occur in the Green River formation of Eocene (early Tertiary) age in northwestern Colorado, northeastern Utah, and southwestern Wyoming. In describing these deposits, Winchester[1] states that in Colorado alone there is sufficient shale, in beds that are three feet or more thick and capable of yielding more oil per ton than the average shale now mined in Scotland, to yield 20,000,000,000 barrels of crude oil and 300,000,000 tons of ammonium sulphate. He estimates that the area in Utah underlain by the Green River formation contains enough shale to produce 42,800,000,000 barrels of crude shale oil, with perhaps 500,000,000 tons of ammonium sulphate as a by-product.[2]

Of 51 samples of oil shale from Colorado tested by Winchester[3] in 1914, 17 samples yielded less than 10 gallons of oil to the ton; 18 samples, between 10 and 20 gallons; 10 samples, between 20 and 30 gallons; 3 samples, between 30 and 40 gallons; 2 samples, 40.6 gallons each; and 1 sample, 65.3 gallons. Of 34 samples from Utah tested in 1915, 6 yielded less than 10 gallons of oil to the ton of shale; 7, between 10 and 20 gallons; 7, between 20 and 30 gallons; 9, between 30 and 40 gallons; and 5, more than 40 gallons. The maximum yield of 90 gallons to the ton was obtained from a thin bed near Watson, Utah. Of 36 samples from Wyoming, 35 yielded less than 30 gallons. Of the remaining 4, a 2-foot bed yielded 50 gallons to the ton.

Beds of oil shale up to 100 feet in thickness are known, but usually such beds are lean. Beds of very rich shale are rarely of any great thickness, often less than two feet. In the thicker deposits, as a rule, lean beds are interstratified with the richer ones and reduce the average oil content of the whole very considerably. Clapp,[4] in a reference to the oil shale deposits of Colorado and Utah, states that the best exposure of oil shale ever examined by a representative of the Associated Petroleum Engineers was 100 feet thick. This averaged 28 gallons to the ton for the entire thickness, but contained one bed 40 feet thick which averaged 40 gallons to the ton.

Gavin and Karrick[5] have prepared the following table representing a tabulation of some of the properties of commercial crude Scotch shale oil and oils made from Scotch and Utah shales in the U. S. Bureau of Mines assay retort as brought out by distillation analyses made in the Bureau's laboratories:—

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[1] Winchester, Dean E., Oil shale in northwestern Colorado and adjacent areas: U. S. Geol. Survey, Bull. 614, p. 141, 1916.

[2] Winchester, Dean E., Oil shale of the Uinta Basin, Northwestern Utah: U. S. Geol. Survey, Bull. 691, p. 28, 1918.

[3] Winchester, Dean E., op. cit. Bull. 641, p. 142.

[4] Clapp, F. G., The relation of the petroleum engineer to the oil shale industry: Associated Petroleum Engineers, Bull. 3, New York, 1920.

[5] Gavin, Martin J., and Karrick, Lewis C., Nature of shale oil obtained from oil-shale assay retort used by the Bureau of Mines, U. S. Bureau of Mines, Report of Investigations, Serial No. 2254, June 1921.

Properties of Commercial Crude Shale Oil

Source of oil	Scotch shale	Scotch shale	Shale from Soldier Summit, Utah	Shale from Soldier Summit, Utah	Pennsylvania crude
Retort	Scotch commercial	assay	assay	assay	
Retorting time		2 hours	2 hours	5 hours	
Yield of oil per ton		18.1 gal.	42.75 gal.	40.2 gal.	
Specific gravity of oil	0.877	0.864	0.896	0.882	0.812
Setting point of oil, deg. C.	28	32	33.5	33	*
Distillation, first drop, deg. C.	49	44	42	40	26
Per cent distilled to 200° C.	12.22	16.63	15.09	18.81	31.93
Unsaturation, 200° C fraction, per cent	28	29.4	42.6	39.2	4.4
Per cent distilled, 200-275° C.	23.22	20.47	19.18	20.10	20.83
Unsaturation, 200-275° C fraction, per cent	34	34.1	43.3	40.2	3.6
Vacuum fraction to 200° C. per cent	9.32	2.10	3.02	2.64	3.33
Specific gravity	0.872	0.868	**	**	0.826
Viscosity	38	38	**	**	39
Setting point, deg. C.	*	*	*	*	*
Vacuum fraction 200-225° C, per cent	5.27	4.38	8.56	7.80	7.75
Specific gravity	0.881	0.872	0.892	0.880	0.832
Viscosity	40	41	41	42	40
Setting point, deg. C.	*	*	*	*	*
Vacuum fraction 225-250° C. per cent	7.16	5.88	9.87	9.20	6.02
Specific gravity	0.892	0.874	0.899	0.889	0.841
Viscosity	46	43	48	48	45
Setting point, deg. C.	24.5	21.5	21.5	18	15.5
Vacuum fraction 250-275° C. per cent	6.13	7.30	10.75	14.90	5.37
Specific gravity	0.902	0.894	0.918	0.906	0.848
Viscosity	52	50	61	58	51
Setting point, deg. C.	29	29	32	31.5	22.5
Vacuum fraction 275-300° C. per cent	6.07	9.45	10.90	8.88	5.16
Specific gravity	0.911	0.898	0.932	0.928	0.859
Viscosity	60	60	53	72	67
Setting point, deg. C.	34	37	40	40	30

* Not determined.
** Combined with next higher cut.

The above distillation analyses show that the oil made from Scotch shale by the assay retort is somewhat superior to that produced in commercial operations in Scotland, except as regards unsaturation percentage. The difference in unsaturation percentage, however, is small. The oil produced from the Green River shale from Soldier Summit, Utah by the assay retort is nearly equivalent to that made from Scotch shale, both by commercial operations in Scotland and by the assay retort in the laboratory, except as regards percentage of unsaturation. This is a quite important point as unsaturation percentage is an indication of the relative magnitude of refining losses. The Soldier Summit shale oil apparently contains a higher percentage of paraffin wax than the other oils examined, as indicated by setting points of the crude oils and percentages and setting points of the vacuum fractions. The Pennsylvania crude is superior to the shale oils except in paraffin content, as indicated by setting points.

In the eastern United States the largest deposit of oil shale[1] is found at one general horizon in the Upper Devonian and possibly in part extending into the Lower Mississippian. It underlies the eastern coal fields and crops out in a long line from central Alabama northeastward through Tennessee and Virginia and all around the Nashville Basin in central Tennessee. West of the Appalachian coal field, its outcrop extends from north to south across central Ohio, passing close to Columbus and reaching the Ohio River near Vanceburg. Thence the outcrop makes a loop through central Kentucky past Lebanon, and northward to Louisville, from which it stretches in a broad belt northwestward across Indiana, past Indianapolis, nearly to Chicago. From this western belt of outcrop the shale extends eastward under eastern Ohio and underlies nearly all of Kentucky except the area within the loop described and all of Indiana west of the outcrop.

Although the total volume of oil shale present is very large, perhaps exceeding that found in the Green River formation of the western United States, the shale is low grade. In very few places thus far sampled and tested has the yield of oil been equal to that obtained from the Scotch shales mined and retorted in recent years.

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[1] Ashley, George H., Oil resources of black shales of the eastern United States, U. S. Geol. Survey, Bull. 641, p. 312, 1917.

Two samples collected by Ashley near Glen Mary, Ohio in 1914 gave 5.6 and 7.7 gallons of oil per ton, respectively. Five samples obtained near New Albany gave yields ranging from 3.5 to 11.9 gallons per ton, the average being 8.1 gallons. Reeves,[1] who has made an investigation of the New Albany shale of Indiana for the Indiana Geological Survey, states that the thickness along the outcrop in that State ranges from 20 to 100 feet. In 7 tests reported by him the yield ranged from 12 to 30 gallons per ton with an average of 18 gallons. Reeves, in his preliminary report, gives the following data on the oil obtained from the New Albany shale of Indiana:

Specific gravity of the oil averages .8900

Fractionation of the oil yields:—

	Per cent.
Up to 150° C.	17.75
150 to 200° C.	11.75
200 to 250° C.	17.75
250 to 300° C.	16.00
above 300° C.	8.50
Coke and tar	28.25

Temperature of carbonization:—Best, 850 to 900° F. (456 to 482° C.)

Ammonium sulphate:—from 5 to 20 pounds per ton.

Total nitrogen in shale:—from .25 to 1.00 per cent.

Gas:— from 500 to 2500 cubic feet per ton.

One sample of the Chattanooga shale from near Louisville, Ky., reported by Ashley in 1917, ran 11.2 gallons to the ton. 19 samples from scattered localities in Kentucky examined by Jillson[2] yield from 8 to 27.75 gallons, the average being 16.1 gallons. 7 samples collected by Ashley in eastern Tennessee gave yields from a trace to 7.7 gallons per ton, while 5 samples from the central portion of the State ranged from none to 9.1 gallons.

Oil shales are found at numerous other geologic horizons and in many other localities in the United States, although not in such extensive deposits as those mentioned. In northeastern Nevada in the vicinity of Elko, an oil shale of probable Miocene age is being exploited that yields an oil exceptionally high in paraffin, so that it is expected that this may be one of the main products manufactured.

Alcohol as Motor Fuel.

Among substitutions for gasoline as motor fuel, ethyl alcohol will undoubtedly play an important role in the future. Ethyl alcohol can be derived from many different sources, among which perhaps various types of vegetation are most important. It, therefore, has an advantage over the various other substitutes already considered in that it can be derived from substances that will replenish themselves from year to year.

Alcohol blended with certain other substances, such as ether, benzene, and gasoline, has already been employed as a motor fuel to a certain extent particularly in localities where gasoline supplies are hard to obtain and their cost is excessive and the raw materials from which alcohol can be made are abundant and cheap.

Boyd[3] has enumerated some of the advantages and disadvantages attending the use of alcohol as a motor fuel as follows:—

Its combustion is marked by clean lines and freedom from any deposition of carbon in the combustion chamber. Because it boils at a definite and comparatively low temperature, it can be well distributed in multi-cylinder motors. On account of its low boiling point it should give no trouble from dilution of crank case oil. Alcohol will stand very high initial compression without knocking and at high compression its combustion is smooth and highly satisfactory. In order, however, to make use of this property a specially designed motor is necessary. Because of the high compression at which alcohol may be used, the available horsepower of a definite size of motor is much greater with alcohol than with motor gasoline, if each be run at its most economical compression.

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[1] Reeves, John R., Data on the New Albany oil shale: Indiana Geol. Survey, 1920. Oil shales of Indiana: Eng. and Min. Jour., Vol. 110 pp. 954-955, 1920.

[2] Jillson, Willard Rouse, A preliminary report on the shales of Kentucky: Kentucky Geol. Survey, Series 6, Vol. 2, p. 7, 1921.

[3] Boyd, T. A., Motor fuel from vegetation: Jour. Ind. and Eng. Chem., Vol. 13, pp. 836-841, Sept., 1921.

Alcohol possesses certain disadvantages as a motor fuel. It has a low heating value, around 80,000 B. t. u. per gallon as compared to about 120,000 per gallon of gasoline. Because of the freedom of alcohol from the tendency to knock, this difficulty may be overcome by initial compressions which are sufficiently high to increase the thermal efficiency so that the output per gallon of alcohol is equal to that of a gallon of gasoline. Such a motor, however, would be a special device which could not run on gasoline, and which, therefore, would not be feasible under present conditions.

The high latent heat and low vapor pressure of alcohol make it hard to start the motor. This difficulty has been overcome by blending with light petroleum oils, for which purpose casinghead gasoline is very suitable. Ether has also been employed for the same purpose.

Alcohol is absorbed by cork carburetor floats, thus rendering them useless. It loosens gummy or other materials deposited in the fuel system and thereby clogs screens in the fuel lines. If alcohol alone, or blended, is used as a fuel it necessitates metal carburetor floats and clean fuel lines.

Alcohol will not blend with ordinary petroleum oils except the very lightest gasoline fractions unless it is either practically free from water or unless a binder or mutual solvent is used. A number of materials have been used to blend 95 per cent alcohol with petroleum oils, of which benzene is probably the best. The unsaturated materials in cracked petroleum oils are effective and cheap, but the final percentage of unsaturation must be kept so low as not to cause motor trouble resulting from the polymerization of such materials to gums or tars. Shale oil gasoline, on account of its high degree of unsaturation, would probably also answer for this purpose.

Care must be taken to keep the alcohol fuel free from acetic acid or there will be corrosion of the storage tanks, tank cars, and the container tanks in the automobile. Acetic acid is also apt to form, particularly if any methyl alcohol is present, through incomplete combustion of alcohol fuels in the engine. Pyridine has been added to such fuels to overcome this difficulty. Aniline can also be used. Unfortunately, both these compounds are rather expensive when compared with alcohol in price.

Thus far the total production of denatured alcohol in the United States has never exceeded 100,000,000 gallons per year, which is not much more than 2 per cent of the total gasoline consumed. The chief source has been the black strap molasses obtained from refining sugar cane. It is not likely, nor is it desirable, that the starch of foodstuffs, at present grown in the United States, be extensively drawn upon to supply alcohol for motor fuel.

Sulphite liquor, obtained from paper mills, as well as the waste wood, such as sawdust from the lumber industry, can be made to yield alcohol. Two plants manufacturing ethyl alcohol from waste wood have been in successful operation in this country for the last few years.[1] These plants obtain a yield of 15 to 25 gallons of 95 per cent alcohol per ton of dry wood at a cost of about 25 cents per gallon. Hawley[2] has estimated that the forests of the United States could under proper management be made to yield sufficient wood for liquid fuel, without encroachment upon the supply of other forest products, to furnish an annual output of 2,475,000,000 gallons of alcohol or about 33 per cent of the total amount of alcohol needed to replace the present output of gasoline.

The process in use at the present time of making ethyl alcohol from waste wood consists in subjecting the cellulose of the wood to the action of very dilute acid at elevated temperatures and under pressure in order to convert it into fermentable sugar from which alcohol can be obtained. Only a portion of the cellulose is thus converted, sufficient to yield from 15 to 25 gallons of alcohol per ton of dry wood. There is a possibility of increasing considerably this yield in the future through further chemical research.

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[1] Sherrard, E. E. Manufacture of ethyl alcohol from waste wood. Chemical Age, New York, Vol. 29, p. 53, 1921.

[2] Hawley, Ralph C. The forests of the United States as a source of liquid fuel supply. Jour. Ind. and Eng. Chem., Vol. 13, pp. 1058-1060, 1921.

The moist tropical regions of the world offer the greatest possibilities of plant growth to furnish materials for liquid fuel. Whitford[1] estimates that from forests of small sized bamboo in the Philippines, 280 gallons of alcohol per acre can be obtained. At that rate an area of 27,000,000 acres, or 42,200 square miles, would be required to produce 7,500,000,000 gallons of alcohol, which is the heat equivalent of the gasoline produced in the United States in 1920. In order to keep up this production indefinitely, an area three times as large, or 81,000,000 acres, would be required, allowing for three-year rotation. It has been estimated that in the Philippines alone there are 68,000 square miles of cut over waste lands in grass and second growth forests that might be made available for such crops.

The production of alcohol from the ethylene present in by-product coke oven and ordinary coal gas has already been mentioned in a previous paragraph.

The synthetic production of alcohol from coal, limestone, water vapor, and sulphuric acid, as developed in Switzerland, also offers possibilities where electric power is sufficiently cheap.[3] Calcium carbide is produced first. Acetylene is obtained from it by the action of water, which may be converted into acetaldehyde and finally by reduction into ethyl alcohol.

CHAPTER III.

BY-PRODUCTS FROM COAL AND SHALE CARBONIZATION.

In the development of a carbonization industry for the production of oils from coal and shale, other products besides crude oil will be obtained that may possess considerable economic value; among the most important of which will probably be ammonia for fertilizer and for refrigerating purposes, gas for heating and illuminating, and spent material remaining in the retort after the carbonization has been completed. The value of the latter will depend upon the character of the material treated. If this is bituminous coal, lignite, or peat it may be the main product and the oil simply a by-product; while in the case of shales, the spent material will probably have little or no value.

Ammonia.

Coals and carbonaceous shale invariably contain small percentages of nitrogen in the form of complex organic compounds. When the coals and carbonaceous shales are carbonized, a portion of this nitrogen is converted into ammonia, part of which goes into solution in the water that condenses with the tar and oil, and part of which passes on with the gas and can be recovered by scrubbing the latter with water or a dilute solution of sulphuric acid.

The per cent of the total nitrogen present in the coal or shale that can be recovered as ammonia in this way depends upon a considerable number of factors. The yield of course is determined in part by the total nitrogen content of the substance treated, also undoubtedly by the character of the combinations in which it exists in the coal or shale. Of still greater importance, however, is the method of carbonization employed. The quantity of ammonia obtained by low-temperature carbonization is considerably less than that obtained from the same material by using high temperatures. The introduction of steam into the retort during carbonization, as is done in the case of the Scotch method, also greatly increases the yield of ammonia.

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[1] Whitford H. N. Possibilities of the plant growth of the moist tropics to furnish material for liquid fuel. Jour. Ind. and Eng. Chem., Vol. 14, pp. 151-152. 1922.

[2] Norman, C. A. Internal combustion engine fuels. Jour. Soc. of Automotive Engineers. Vol. 10, pp. 187-192. 1922

Ammonia has a considerable number of uses, among which by far the most important is its application to the soil as a fertilizer. For this purpose it is converted into the sulphate. Plants require nitrogen in the form of some soluble compound. At present ammonium sulphate obtained from by-product coke and coal gas plants and sodium nitrate imported from Chile, are the chief sources of such nitrogen for commercial fertilizers in the United States. Another important application of ammonia is in the modern practice of refrigeration, for which large amounts of anhydrous ammona gas are required. Ammonia in solution is employed for cleaning purposes. Processes have been evolved by which ammonia can be oxidized into nitric acid which finds extensive use in the manufacture of explosives. Ammonia is also used in the manufacture of baking soda, and considerable quanities are consumed by the dye industry.

The chief sources of ammonia at present utilized in this country and abroad are by-product ammonia, obtained by the destructive distillation of coal, peat, and oil-shale, either without the admission of air as in by-product coke ovens and coal gas retorts, or with limited amounts of air and steam or steam alone as in gas producers or in the Scotch shale retorts; cyanamide ammonia, obtained by the action of steam or superheated water on calcium cyanamide, which is formed when nitrogen is passed over heated calcium carbide; ammonia from nitrides, such as aluminum nitride, which is treated with steam to produce ammonia in the Serpek process; and synthetic ammonia, obtained by the direct combination of nitrogen and hydrogen in the Haber process.

In the United States, almost the entire production comes from the first source, being furnished by the by-product coke and coal gas plants. In 1918, the by-product coke plants of the United States marketed 697,308,770 pounds of ammonium sulphate or its equivalent, valued at $26,412,951.[1] The average price received per pound, therefore, was 3.8 cents. This amount of ammonium sulphate was obtained from 36,867,721 tons of coal, making the average yield per ton 18.9 pounds. Ammonia was the most important by-product in point of value produced in 1918, the receipts from its sale being $1.02 per ton of coke produced, while the total for all by-products sold was $2.87. The coal-gas plants of the United States sold 56,900,464 pounds of ammonium sulphate or its equivalent in 1918, valued at $1,453,070, the average price per pound being 2.6 cents.[2] A total of 59,348,144 pounds was produced during that year from 4,966,672 tons of bituminous coal, the average yield per ton, therefore, being 11.9 pounds. Before the World War the price of ammonium sulphate varied in general, between 2½ and 3 cents per pound.

In the United States, the chief competitor of ammonium sulphate for fertilizer purposes is sodium nitrate. In 1918, 2,069,379 short tons, valued at $90,216,935, were imported from Chile.[3] This amount contains the same quantity of fixed nitrogen as 1,609,138 tons or 3,218,276,000 pounds of ammonium sulphate, assuming that the material is nearly pure. Its value therefore, is equivalent to a price of 2.8 cents per pound for ammonium sulphate.

White,[4] after a rather careful and thorough investigation of the demand and supply of fixed

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1. U. S. Geol. Survey, Mineral Resources, 1918, Part II, pp. 1501, 1521, and 1523, 1921.
2. Artificial gas and by-products in 1917-18. U. S. Geol. Survey, Mineral Resources, 1919, Part II, pp. 484 and 505, 1921.
3. U. S. Geol. Survey, Mineral Resources, 1918, Part II, p. 188, 1921.
4. White, Alfred H. The demand and supply of fixed inorganic nitrogen in the United States: Chem. and Met. Eng., Vol. 22, pp. 369-371, 1920.

inorganic nitrogen in the United States has made the following forecast for 1930.

Demand for 1930 based on normalized 1913 figures with increase of 7 per cent compounded annually . . .	=	458,200 tons of fixed nitrogen
Sources of supply.		
Domestic coke-ovens, gas retorts, and private cyanamide plants with assumed increase of 40 per cent over 1920 . .	=	130,000 tons
Balance to be made up	=	328,200 tons
Equivalent in ammonium sulphate	=	1,549,104 tons

The above figures would indicate that there will be abundant demand for all ammonium sulphate that may be produced by the low-temperature carbonization of coal, or through the development of an oil shale industry for a considerable time. It remains to be seen, however, whether economical methods of retorting can be devised which will yield amounts sufficiently large to pay to recover the ammonium sulphate at prevailing prices. It is not likely, at least for many years to come, that the production of synthetic ammonia from nitrogen of the atmosphere will be a factor in still further depressing the price.

With low temperature carbonization carried to a temperature not exceeding 482° C. (900° F.) the yield of ammonium sulphate will probably be less than one-half that obtained when the same coal is carbonized in the by-product coke oven at high temperatures. Under the former conditions, the writer obtained yields ranging from 4 to 13 per cent of the total nitrogen content of the coal, while when the temperature was run up to 760° C. (1400° F.), the yield was increased to from 14 to 23 per cent of the total nitrogen present in the coal. Bone[1] states that the yield of ammonium sulphate per long ton (2,240 pounds) to be expected from low-temperature distillation (450 to 550° C.) ranges from 5 to 7 pounds, while with high temperature distillation (900 to 1100° C.), it varies from 20 to 30 pounds.

The Scotch, in the development of their oil shale industry, have made a special effort to obtain a maximum yield of ammonium sulphate and it is claimed that it was only by doing so that the oil shale industry was able to survive during the period prior to 1913. In order to accomplish this, the temperature in the lower part of the retort is raised to 815° C. (1500° F.) and about 105 gallons of water, as exhaust steam, are admitted for each 25 gallons of oil produced. In this way the yield of ammonia is increased about two and one-half times as compared with dry distillation.[2] Shale now being minded and retorted in Scotland by this method yields about 36 pounds of ammonium sulphate per ton of 2,000 pounds.

Gas.

In the low-temperature carbonization of coal it is not likely that any very large excess of gas over that required to heat the retorts will be obtained and in the installation of such plants it is probably best not to figure on any surplus. Davis[3] believes that it is probably safe to assume the yield for fair gas coals at between 5,000 and 6,000 cubic feet per ton of 650 to 750 B. t. u. gas. The writer obtained yields at the rate of 3,200 to 5,500 cubic feet per ton from a number of different bituminous coals carbonized on a laboratory scale at temperatures not exceeding 482° C. (900° F.).

With the by-product coke oven the yield of gas is greatly increased at the expense of oil and tar production so that an oven of the Koppers type, using part of its gas production for its own heat-

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1. Bone, William A. Coal and its Scientific Uses, p. 133, London, 1919.
2. Gavin, Martin J., The necessity for research in the oil-shale industry: Chem. and Met. Eng., Vol. 23, pp. 490-491, 1920.
3. Davis, J. D., Present status of carbonization at low temperature: Report of the Carbonization Committee, American Gas Association, p. 21, 1921.

ing requirements, still delivers a surplus, amounting to 60 per cent or even more of the total gas. This surplus is about 6,600 cubic feet per net ton of coal charged and, after the recovery of benzenes, the gas has a heating value of 560 B. t. u. per cubic foot.[1]

In the carbonization of shales, there is even less likelihood of obtaining any surplus of gas than in the low-temperature distillation of coal. In many instances, particularly with low grade shales, it will probably be found necessary to use some auxiliary fuel to heat the retorts.

In Scotland, by increasing the temperature of the lower retort and admitting steam, the volume of gas is increased, but its heating value is not anywhere near that of coal gas. The average yield from the shales at present run to the retorts is approximately 10,000 cubic feet per ton, having a heating value of about 240 B. t. u. per cubic foot.[2] This gas is employed in heating the retorts. In the case of some shales retorted, it is not sufficient to supply all the heat required and has to be supplemented by producer gas.

The gases evolved during the oil formation stage of carbonization contain considerable percentages of unsaturated hydrocarbons from which valuable chemical products may be derived. The possibility of producing ethyl alcohol from ethylene, an unsaturated hydrocarbon present in shale as well as coal gas, has already been mentioned.

Spent Material.

The spent material obtained from the carbonization of coal makes a valuable fuel. In the case of the major portion of the coal treated in by-product ovens, the primary object is to obtain a metallurgical coke. In the case of the coal gas industry, the coke obtained is in part sold as fuel for domestic and other purposes, while in part it is used in the manufacture of carbureted water gas.

The successful establishment of a low-temperature coal carbonization industry will depend in large part upon the development of a demand for a smokeless fuel suitable for domestic and other uses. The gradual exhaustion of the anthracite deposits of Pennsylvania and the consequent increase in cost of this valuable fuel to the consumer and also the depletion of the natural gas resources of the Appalachian region, ought to be important factors in bringing about the establishment of such an industry in the Eastern United States in the near future.

Many types of bituminous coals, including some that do not produce a satisfactory metallurgical coke, yield a low-temperature coke when carbonized under slight compression. This happens when the coal is carbonized in a limited space so that it cannot expand too freely. The coke contains from 5 to 15 per cent of volatile matter, is easy to burn without smoke, ignites readily, and makes an ideal domestic fuel. The residues obtained from other coals, including those of sub-bituminous and lignitic rank, will probably have to be briquetted before they can be used for fuel. For this purpose, the pitch obtained from the fractional distillation of low-temperature tars can be used. With high volatile coals a sufficient quantity of binder will probably be formed to briquet the entire residue. This is the procedure employed at the 200-ton per day "Carbocoal" process plant at Clinchfield, Virginia.[3] The primary retorts used in this process yield a light friable coke which is subject to spontaneous combustion. This coke is briquetted, using the pitch obtained from the low-temperature tar as a binder, and then further carbonized in another type of retort to 1800° F. The resulting fuel is in every respect equal, if not superior, to antharcite for domestic purposes. The problem is to still further reduce the cost of manufacture so that the coke briquets can compete successfully with other types of fuel. Another outlet for at least a portion of the residues may be found in the manufacture of producer gas for use about the plant or for conversion into electric power.

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[1] Sperr, Jr., F. W. and Bird, E. A., By-product coking: Jour. Ind. and Eng. Chem., Vol. 113, p. 29, 1921.

[2] Gavin, Martin J., op. cit. p. 491.

[3] Curtis, Harry A., The commercial realization of the low-temperature carbonization of coal. Jour. Ind. and Eng. Chem., Vol. 13, pp. 23-26, 1921.

The disposal of the spent shale, resulting from the carbonization of oil shales, is a more serious problem. In most instances, probably no commercial uses for it will be available and dumping sites for its disposal will have to be provided in laying out plants. In densely populated sections and places where ground is valuable for agricultural and other purposes, this may prove to be a difficult problem to solve in locating such plants.

Among many possible uses for such material that have been suggested, the manufacture of brick and Portland cement probably offer the greatest possibilities. The number of plants, however, that can hope to utilize their spent material in this manner will be very limited. There will have to be a good market for these products in the immediate vicinity, and the other raw materials entering into their manufacture will have to be near at hand.

Some shales and particularly materials like cannel coal may yield a residue which, although not suitable for ordinary fuel on account of its high ash content, may yet contain sufficient fixed carbon to enable it to be used in gas producers for the manufacture of gaseous fuel. The degree of refractoriness of the resulting ash will be an important factor in this case. In the Scotch process, the steam introduced into the lower hot part of the retort consumes the major portion of the fixed carbon with the formation of gaseous fuel. The spent material discharged from the retort, contains only from 1½ to 2 per cent of fixed carbon.

Practically all oil shales contain small amounts of potash in the form of insoluble compounds. At the temperature to which the shale is subjected in the retorting process, a portion of this potash may be rendered water soluble and, therefore, suitable for extraction by leaching with water. George[1] states that analyses of the spent shale from Parachute and Conn Creek valleys of western Colorado showed an average water soluble potash (K_2O) content of about 0.9 per cent or about 18 pounds per ton of spent shale. The range of water soluble potash, shown by the analyses, was from 0.25 to 2.02 per cent. There is a commercial possibility, therefore, in the case of some shales of recovering potash from the spent material. The problem of disposing of the refuse, however, would still remain the same.

In the Phosphoria formation of the Permian in the vicinity of Dillon and Dell in southwestern Montana, oil shales occur which, although not phenomenally rich in oil, are phosphatic in character so that there is a possibility that the residue may have some value as a source of phosphate for fertilizer purposes.[2]

By-products from Coal and Shale Oils and Tars.

Attention has already been called to the great number of very valuable organic chemicals that are manufactured at the present time from the coal tars produced by the by-product coke and coal gas industries. No doubt a great many organic compounds can likewise be derived from the low-temperature coal tars and shale oils, some of which already have commercial applications or for which uses will be found in the future.

Low-temperature coal tars contain large percentages of phenolic compounds for which numerous uses already exist. The oils obtained from the low-temperature tars produced by the "Carbocoal" process at Clinchfield, Virginia, have thus far been used largely by manufacturers of disinfectants on account of their high content of these constituents.[3] Many shale oils contain high percentages of paraffin wax.

In the establishment of a low-temperature carbonization industry on an extensive scale, however, too much reliance should not be placed at least in the immediate future, upon profits to be derived from the production of minor by-products. While a great number of useful organic compounds can undoubtedly be made the total annual consumption of many of these is relatively small, so that an over production can readily be brought about with a resulting drop in prices. Also, many of these compounds require so much technical skill in their manufacture that, while they command a relatively high price, their cost of production is also high. The greatest demand is for such products as motor fuel, kerosene, lubricants, and fuel oils. It is in these fields that an outlet for the major portion of the oils and tars of the carbonization industry will have to be sought if it is to be developed on a large scale.

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[1] George, R. D. Oil shales of Colorado, Colorado Geol. Survey Bull. 25, p. 59, 1921.

[2] Condit, D. Dale., Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah, U. S. Geol. Survey Bull. 711, pp. 15-40, 1919.

[3] Runge, Walter, Products of low-temperature distillation of coal: Chemical Age, Vol. 30, pp. 9-10, 1922.

CHAPTER IV.

THE OCCURRENCE, COMPOSITION, AND ORIGIN OF COAL AND CARBONACEOUS OR OIL SHALE DEPOSITS.

Coals and carbonaceous or oil shales contain organic materials derived largely from plant remains which have undergone partial decomposition and which are more or less intimately mixed with varying amounts of mineral matter. The organic substances consist of highly complex compounds containing carbon, hydrogen, oxygen, nitrogen and, in some cases, sulphur. Upon the application of heat without access to air, these substances undergo partial decomposition with the formation at first, at least in the case of many oil shales, of a heavy solid or semi-solid bitumen,[1] but finally break up into simpler forms which pass off as vapors. Upon cooling, oils, tars, and ammoniacal liquor are condensed from these vapors, while a certain percentage remains as permanent gas, not condensable at ordinary temperatures.

As a rule when an organism, either plant or animal, perishes, it is at once attacked by bacteria and scavenging animals and the orgnic materials of which it is composed are consumed and disappear. If the organism dies on the land where its remains are exposed to the atmosphere, the oxygen of the air assists in this process; and if under water, oxygen in solution plays the same role, but in this case the process leading to complete destruction is much slower. The process is much more rapid in animal than in plant remains, so that organic materials of plant origin are much more apt to become entombed in sediments than are those of animal origin.

Under certain favorable conditions, such as in shallow, stagnant seas, particularly enclosed bodies such as the Black Sea; in marine marshes and lagoons; shallow fresh water and to a limited extent saline lakes and swamps; bogs; and wet woods where only limited supplies of oxygen are available, considerable amounts of organic material, particularly those of plant origin, may accumulate, mingled to a greater or less extent with finely divided mineral matter brought in by streams or the winds and deposited along with the slowly accumulating organic debris. Grabau[2] calls attention to certain loesslike deposits in southern Russia, the upper part of which, for 20 feet or more, is colored black by a thorough admixture of organic matter. This black earth appears to represent the accumulation of fine dust among actively growing herbaceous vegetation. The organic matter forms ten or more per cent of the black earth. The tundras of the arctic region also are favorable areas for the extensive accumulation of fairly pure vegetal matter.[3] The short arctic summers are warm and develop a very vigorous growth of mosses and stunted higher types of vegetation over the treeless plains, while a foot or so below the surface the ground is pereptually frozen. Innumerable pools of standing water dot the fairly level surface and decay is very much retarded.

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[1] McKee, Ralph H. and Lyder, E. E., The thermal decomposition of shales. I. Heat effects: Jour. Ind. and Eng. Chem., Vol. 13, p. 625, 1921.

[2] Grabau, Amadeus W., A textbook of geology, Part I, p. 459, New York, 1920.

[3] Kemp, James F., The economic geology of the non metallic minerals. Privately printed, p. 6.

If any of the above deposits are later buried underneath sediments such as muds and sands, as would happen in the case of an area that was undergoing gentle subsidence, they give rise to deposits of coal or carbonaceous shales, depending upon the amount of mineral matter present in them.

The quantity and chemical character of the oils and other by-products which can be derived from such materials depends upon a considerable number of factors, including the nature and composition of the original organic debris, the amount of mineral matter deposited with it, the amount and nature of the decomposition which it underwent before burial, the changes that geological processes have produced in it since that time, and finally the temperature of the destructive distillation to which it is subjected.

Among primary deposits of sedimentary origin, coals are perhaps the richest in organic matter. They consist almost entirely of plant debris, animal remains being practically absent. Mingled with the organic debris are small percentages of inorganic sediments which, together with the original mineral matter contained in the plants themselves, constitute the ash of the coal.

Careful studies of the geological occurrences of coal deposits and microscopic examinations of the coals themselves have proven conclusively that they have been derived from deposits of peat, similar to those that are accumulating in fresh water swamps at the present time. For the formation of coal, however, it was not only necessary that rather extensive deposits of peat accumulated, but also these had to be in positions where they later on became buried underneath sediment which preserved them from erosion. The most favorable places for this to occur are in broad shallow depressions on extensive, nearly level, low-lying coastal plains, along the flood plains near the mouths and on the deltas of large rivers.

The first step in the formation of coal from vegetal matter takes place when the dead vegetation, through loss of moisture and partial decomposition, is converted into peat in the swamp. It loses a certain amount of its oxygen, hydrogen, and carbon in the form of carbonic acid (CO_2) and march gas (CH_4) and also part of its water of constitution. Bacteria probably play a very important role in this process of disintegration. The process does not always reach the same stage of completion before the peat is buried by sediments. Sometimes, therefore, the peat from which the coal has been derived was woody or fibrous, while in other cases it was a more or less jelly-like, amorphous mass through the obliteration of most of the plant structures. The next step in the formation of coal is the burial of the peat underneath a constantly increasing load of sediment washed over the gradually subsiding swamp by streams. Under these conditions, the peat becomes further compacted; moisture and gases, principally marsh gas, CH_4, carbon dioxide, CO_2, and carbon monoxide, CO, continue to be expelled and the peat is slowly converted into coal. Lateral pressure, brought about by mountain making movements produced through the gradual shrinkage of the earth, may further accelerate these changes. The peat may pass through various stages from lignite through sub-bituminous, bituminous, semi-bituminous, and semi-anthracite coal until finally it is converted into anthracite or even into graphite if the process of metamorphism goes on to completion. These changes result in the expulsion of a large part of the moisture, oxygen, nitrogen, and hydrogen, together with varying amounts of the carbon of the original peat. Most of the carbon, however, remains behind. Deposits representing all stages of plant carbonization from peat to graphite are known. In Pennsylvania only the later stages from bituminous to anthracite are represented in the coal bearing formations.

The resulting coal usually shows in cross-section alternate layers of "bright" and "dull" coal. Sometimes a third variety, known as mineral charcoal or "mother of coal," is also present. This is porous in structure and shows abundant traces of plant remains.

Thiessen's[1] detailed and comprehensive studies of coals under the microscope have shown that the "bright" coal has been formed from the large limbs and trunks of trees or parts of them, which were not disintegrated in the peat swamps prior to their burial underneath a protecting mantle of sands and silts. This "bright" coal retains its original woody structure, although often somewhat distorted. The "dull" coal consists of numerous small layers or chips of "bright" coal embedded in a dull matrix, the attritus. These small chips are derived from fragments of larger woody chunks, small stems and branches, twigs, roots, etc.

The dull matrix or attritus, has been derived from a variety of materials, including the waxy cuticle covering of the leaves, an extremely resistant substance; from spore and pollen exines or cases; from resinous and woody matter in different states of carbonization and from small amounts of gums, pectins, and corks or pieces of bark. Photomicrographs (Plate II A and B) show the appearance of typical bituminous coal in thin sections under the microscope.

In the usual or proximate analysis of coal, the constituents present are grouped under moisture, volatile matter, fixed carbon, ash and sulphur. Under the term moisture is included only the more or less loosely held water which is driven off when the finely powdered coal is heated slightly above the boiling point of water, about 105° C. or 220° F. The volatile matter represents that portion of the coal, exclusive of moisture, which can be driven off in the gaseous or vapor form when the coal is heated to a high temperature out of contact with air. It is the volatile matter that furnishes the oils, tars, gases, and ammonia, as well as part of the water of the ammoniacal liquor. The quantities of these various products which can be obtained from a particular coal, therefore, are in part a function of the percentage of volatile matter that the coal contains. The fixed carbon is the residue left after the moisture and volatile matter have been expelled and the percentage of ash has been subtracted. The latter is the mineral residue left after the coal has been completely burned.

The mineral residue of the coal is in part derived from the small inorganic content of the plant remains from which the coal has been derived and in part from sediments brought to the swamp in suspension or solution by streams or blown over it by winds and deposited with the peat. The latter material predominates in most coals.

The percentage of ash in high grade coals ranges from 4 to 7; in ordinary coals, from 7 to 14; and in inferior coals, still higher. High ash coals are referred to as "bony" coal or simply as "bone" in case the ash content has become so high that they are no longer of any commercial value as fuel. Finally, there are cases in which the percentage of mineral matter exceeds that of the organic matter and the deposit is a black carbonaceous shale.

Ordinary bituminous coals, when subjected to low-temperature destructive distillation, i. e., 500 to 600° C., yield a crude oil or tar which has a specific gravity of approximately 1.0, the exact value usually being a little above rather than below that figure. This tar contains large percentages of tar acids or phenolic compounds, soluble in a 10 per cent caustic soda solution, as compared with the oils or tars obtained from cannel coals or most oil-shales under similar conditions of carbonization These phenolic compounds are probably derived largely from the "bright" coal which consists of woody or cellulosic material. The "dull" coal is apparently the chief source of the paraffin, naphthene, olefine, and other hydrocarbons present in the crude tar. The bone and carbonaceous shales of the type described above yield similar oils, but in smaller quantities.

Layers of bone and carbonaceous shale frequently occur as partings in coal beds or overlie them. Such layers represent intervals when excessive quantities of fine silt and mud were

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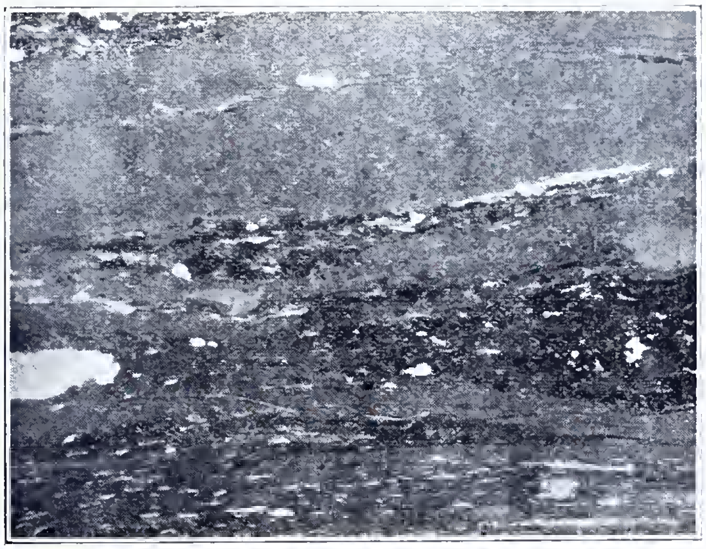
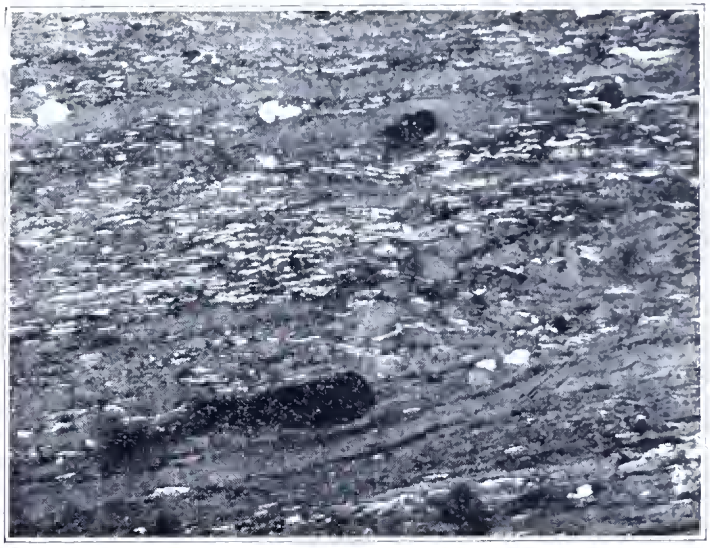
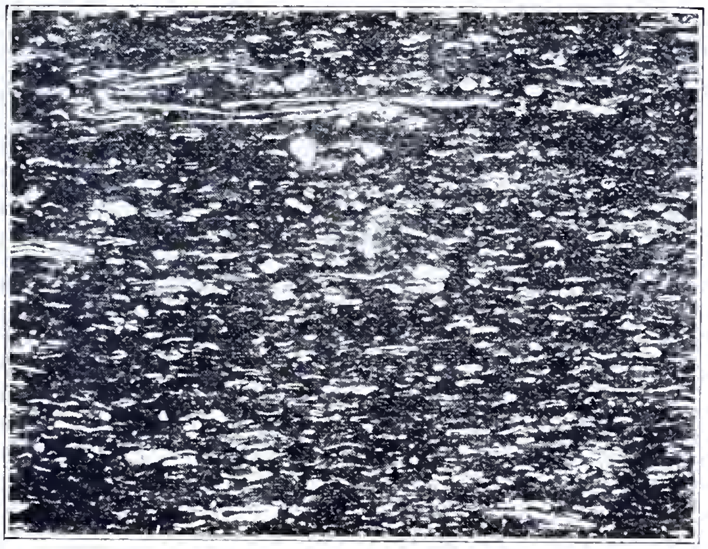
[1] Thiessen, Reinhardt. Compilation and composition of bituminous coals: Jour. Geology, Vol. XXVIII, p. 205. 1920.



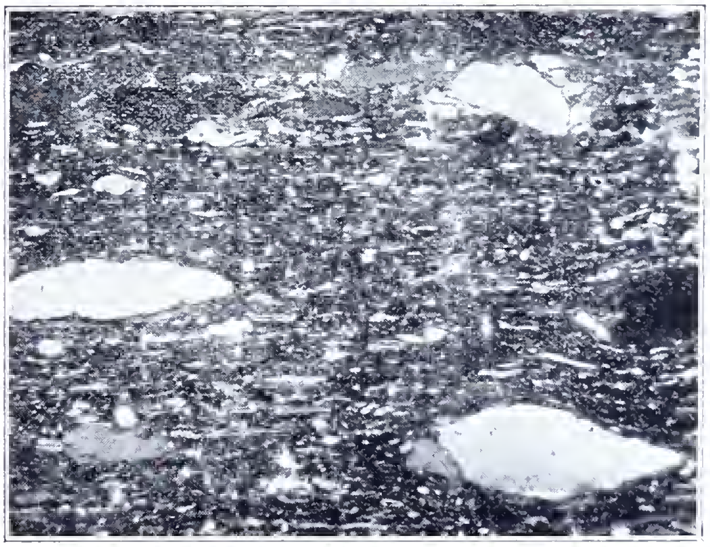
A. Photomicrograph of bituminous coal, Pittsburgh bed, showing woody tissue and a few flattened spores. Magnified 200 times. (Courtesy R. Thiessen)



B. Photomicrograph of bituminous coal, Pittsburgh bed, showing numerous flattened spores as white lines and some woody tissue. Magnified 200 times. (Courtesy R. Thiessen)

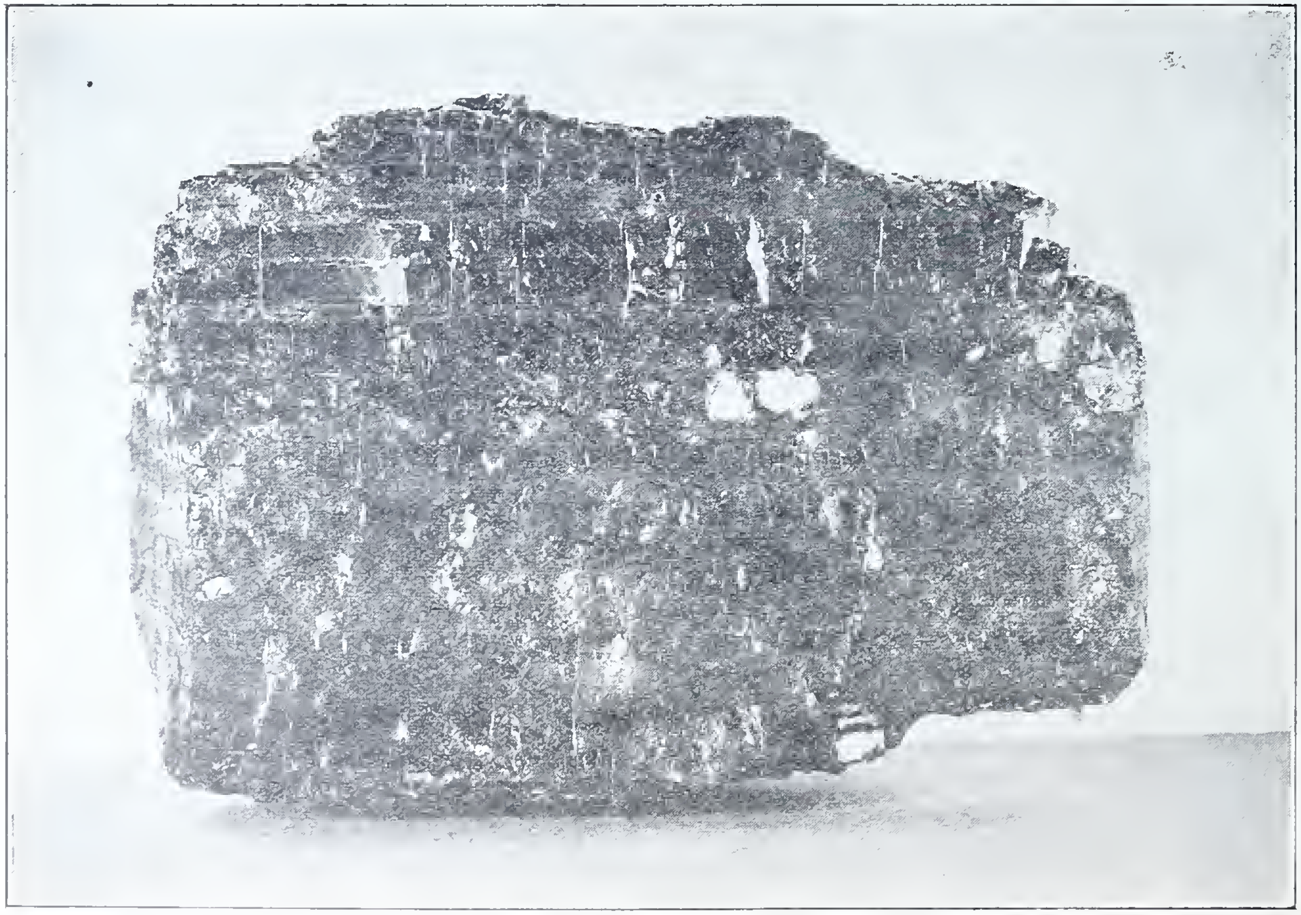


C. Photomicrograph of cannel coal, Upper Kittanning horizon, Paragon Coal and Coke Company's mine, Cannelton, Pa. A typical spore cannel coal in which fully 90 per cent of organic matter consists of flattened spore exines and macerated spore matter. Magnified 200 times. (Courtesy R. Thiessen)



D. Photomicrograph of cannel shale, Upper Freeport horizon, Diamond Coal and Coke Company's Oakmont No. 1 mine, Barking Station, Pa. Composed largely of woody degradation or humic matter and some spores. Magnified 200 times. (Courtesy R. Thiessen)

A. Cannel coal.



B. Bituminous coal. (Courtesy U. S. Bureau of Mines) washed over the slowly subsiding swamp area during the period of peat formation. In mining the coal they are left behind in the gob or else have to be separated later on by hand picking or mechanical means. At present they have no commercial value.

Besides the ordinary type of coal derived from the woody or peaty material accumulating in peat marshes, there is another variety, commonly known as cannel coal, which has a fine, even, compact texture, black color, dull luster, and conchoidal cross fracture. In mining it usually breaks off in rudely rectangular blocks of varying dimensions. The contrast in appearance between cannel and an ordinary bituminous coal is shown in Plate III.

Cannel coals have a relatively high percentage of volatile matter compared to their fixed carbon content, higher, as a rule, than that of the ordinary coals of corresponding rank. For that reason when they are subjected to low-temperature distillation the amount of oil obtained from them is considerably greater than that obtained from ordinary coals. This oil has a lower specific gravity than the low-temperature tar produced from the latter, ranging in most cases from about .9 to .95. Its content of phenolic compounds is also considerably less.

Microscopic study has shown that cannel coals are derived from water-laid deposits made up of plant spores, pollen grains, minor amounts of resin particles, seed coats, waxy bodies, etc., together with the more or less disintegrated and decomposed remains of low order water plants. Remains of fish and other free-swimming animals have also been found in some cannel coal deposits, but these have in no case furnished more than a very insignificant percentage of the total organic debris. Woody or peaty material, which enters so largely into the composition of ordinary coal, is practically absent. In other words, cannel coals resemble rather closely in composition the "dull" layers of ordinary coal.

All cannel coals are not alike in composition although they resemble one another closely in physical appearance. Some contain very little else than spore matter. Others have varying amounts of other plant degradation matter present in addition to the spore cases, while still others are made up largely of what may prove to be algal remains.[1] Associated with the organic material, just as in the case of other coals are varying amounts of mineral matter or ash. Plate II C and D and Plate IV A and B show photomicrographs of several types of cannel coal.

The essential difference betwen cannel and ordinary coals lies in the nature of the plant debris from which the two are derived. From the character of the cannel coals, their mode of occurrence, and the shape and relation of their deposits to ordinary coals, it appears that most cannel coal deposits were laid down in open-water basins or channels in peat forming swamps. Such open bodies of water in a swamp would gradually become filled by material of the type that the microscope has revealed to be present in cannel coal. Winds would blow spores, pollen grains, seeds, etc., into such bodies of water from the surrounding marsh. Algae and other types of floating plants would thrive in them.

As a rule, cannel coals have a higher ash content than ordinary coals. This is undoubtedly due to the fact that fine silt finds its way more readily into bodies of open water than into the dense growth of vegetation of the ordinary peat marsh. In the case of cannel, as in the case of ordinary coal, there are found all gradations from nearly pure cannel coal, through cannel shale to carbonaceous shale. Carbonaceous shales of the cannel type, however, give a considerably higher yield of oil than those more closely related to the ordinary type of coal with the same percentage of organic matter. This is due to the original difference in composition of the vegetal matter from which the two are derived.

Cannel coals, after they have been buried underneath a load of sediments and subjected to

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1. Oral communication. Thiessen, Reinhardt.

earth movements, have undergone changes similar to those which have taken place in ordinary coals and, as a result, the ratio of the percentage of fixed carbon divided by the percentage of volatile matter, which is known as the fuel ratio, increases. Ashley has, therefore, classified cannel coals into brown sub-cannel of lignite rank, black sub-cannel of sub-bituminous rank, cannel of bituminous rank, and canneloid of semi-bituminous, semi-anthracite, and anthracite rank.[1] In the case of the canneloid varieties the percentage of volatile matter, as compared with the fixed carbon, is too low to yield any very large amount of oil on carbonization.

Cannel coal deposits rarely have a horizontal extent comparable to that of many ordinary coal beds. The carbonaceous and cannel shales sometimes found associated with them, however, often extend over larger areas than the cannel coals themselves. Bituminous coal frequently occurs associated with the cannel in the same bed.

Oil shales are very closely related to cannel coal in origin. They do not contain oil as such, but the oils distilled from them are derived from the organic matter contained in them. This organic matter in all the well known deposits consists practically entirely of plant rather than animal remains.

Thiessen,[2] through microscopic studies, has found that there is a marked similarity in composition between the cannel shales of the Pottsville of Kentucky, the oil shales of the Devonian of Illinois, Indiana, and Kentucky, and the Scotch oil shales. The cannel shale from the Pottsville at Wrigley, Kentucky was found to be similar in composition to cannel coal except that it contains a greater content of mineral matter. The organic debris consists largely of spores, some cellulosic or woody degradation and a little resinous matter. The oil shales of the Devonian of Kentucky have a similar composition, but contain a still larger proportion of mineral matter and less recognizable cellulosic degradation matter and still less resinous matter. The oil shale of the Devonian of Illinois is similar to those of Kentucky and Indiana, but contains little or no resinous matter. The Scotch shale contains a slightly larger number of larger resinous-appearing dark brown bodies of a roughly rounded shape than the Devonian shales of Illinois, Indiana, and Kentucky. Plate IV, C and D represent photomicrographs of typical oil shales.

The oil shales of the Green River formation of Colorado, Utah and Wyoming and the Miocene oil shale near Elko, Nevada appear to differ considerably from the Devonian oil shales of the eastern United States in composition, structure, and physical characteristics. Plant debris, however, is also the source of the organic matter in them. George[3] states that shreds of plants, fragments of fruits or seeds, pollen grains, and spores are often so numerous in thin sections of Colorado shale examined as to occupy more than half the field of the microscope. Cell structures are, in some cases, beautifully preserved.

It is seen, therefore, that coals and carbonaceous shales all contain partially disintegrated and decomposed organic remains, chiefly of plant origin. These have undergone various stages of alteration since their deposition; the amount depending upon the geological age of the deposits their depth of burial, and the nature of the earth movements through which the area in which they occur has passed since the period of deposition. The nature and quantity of the oils, gases, and other by-products that can be derived from them by any particular process of treatment, is determined to a large extent by the composition and state of decay of the organic material which entered into the original deposit, and the amount of alteration or metamorphism that the deposit has since undergone, as well as the amount of the mineral matter that occurs mixed with the organic debris. Finally, the mode of treatment to which the coal or shale is subjected, particularly the temperature at which carbonization is carried on; has a pronounced influence on the derived products.

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[1] Ashley, George H. Cannel coal in the United States. U. S. Geol. Survey Bull. 659, p. 10, 1918.
[2] Thiessen, Reinhardt., Origin and composition of certain oil shales: Economic Geology, Vol. XVI, pp. 289-300, 1921.
[3] George, R. D., Oil shales of Colorado: Colorado Geol. Survey, Bull. 25, p. 23, 1921.

CHAPTER V.

COAL AND CARBONACEOUS SHALE DEPOSITS OF PENNSYLVANIA.

Carbonaceous shales are present in Pennsylvania in formations of Devonian, Mississippian, Pennsylvanian, and Permian ages. Although coal makes its first appearance in the Mississippian, it does not occur in beds of minable thickness below the Pennsylvanian.

Some of the shaly beds of the Devonian contain sufficient carbonaceous material to give them a black color. This is true of portions of the Onondaga formation of Middle Devonian age in south central Pennsylvania and of the Burket black towards the northeast along the Pennsylvania Railroad between Altoona and Bellwood. shale of the Upper Devonian, which is particularly well exposed in and about Altoona in Blair county, also for 20 miles to the southwest, and

A dozen or more thin streaks of carbonaceous shale and seams of coal from one to six inches thick occur in the gray sandstone of the Pocono formation of the Mississippian period in central Pennsylvania, but nowhere do these attain a minable thickness.

All of the important coal beds of the State, including cannel coal as well as most of the prominent occurrences of carbonaceous shales, are confined to formations of Pennsylvanian age. These strata extend over the major portion of western Pennsylvania, as is brought out in figure 3, and at numerous horizons contain beds of coal or carbonaceous shale. Several beds of coal also occur in rocks of Permian age in Washington and Greene counties, in the southwest corner of the State but these are only of minor importance as far as thickness and horizontal extent are concerned.

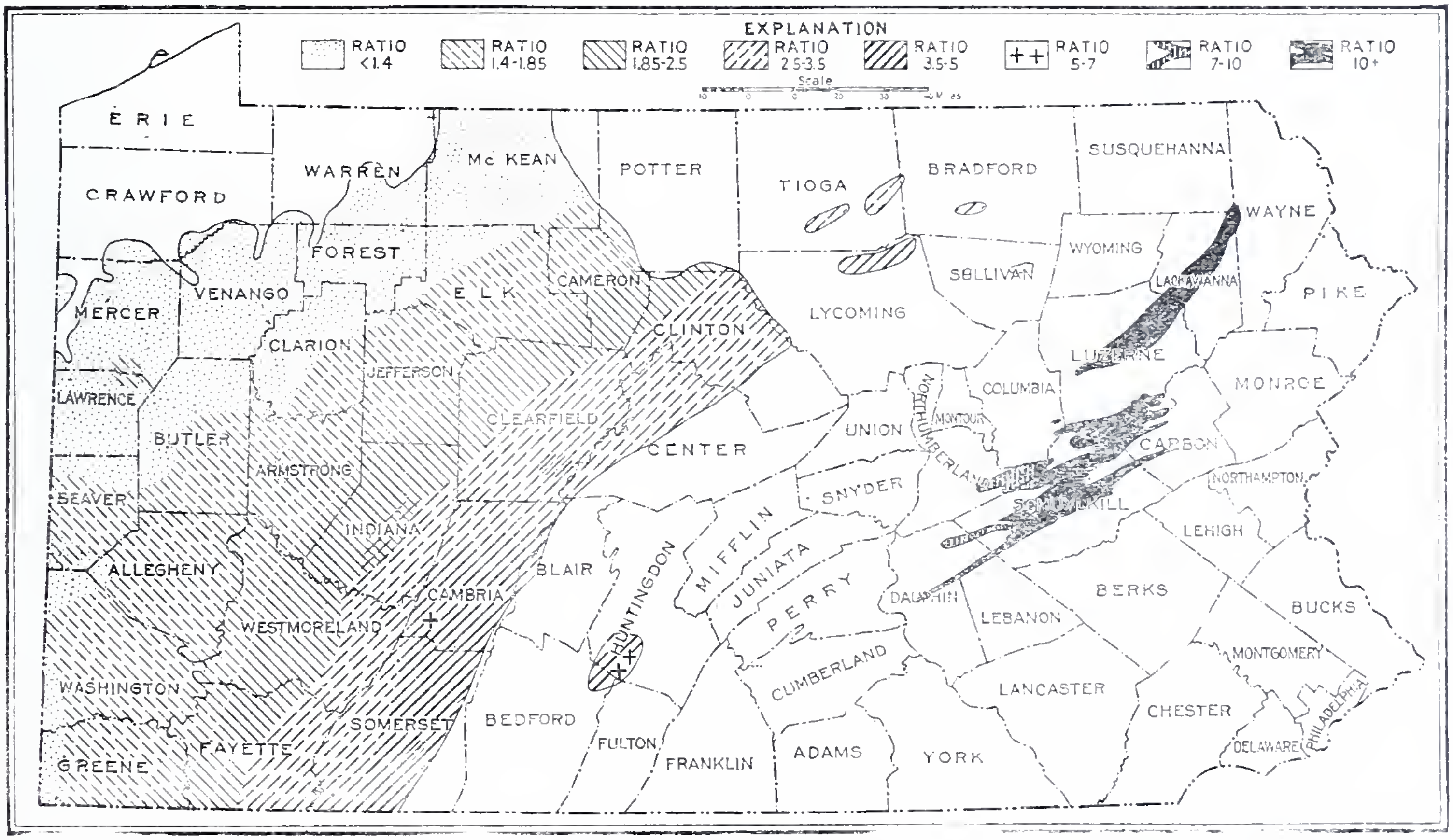

FIGURE 3. Map of Pennsylvania, showing distribution of coals by fuel ratios. (Prepared by G. H. Ashley, 1908. New map based on more data is in preparation).

Stratigraphy of Pennsylvania Coals.

The more important of the coal and carbonaceous shale beds of the Pennsylvanian and Permian periods are confined to rather well established definite horizons or levels in the formations belonging to those periods. These horizons can often be traced over rather widespread areas, not only in western Pennsylvania but also over adjoining parts of Ohio and West Virginia. It is common for coal to occur alone, but coal and carbonaceous shale may occur together, and in some places a horizon may be represented by carbonaceous shale alone or organic materials may be entirely absent. The cannel coal and shale deposits of the State also occur at these horizons.

The coal horizons of the Pennsylvanian and Permian formations from the top down, with the approximate intervals between them as developed in western Pennsylvania, are given in the following table.

Coal beds of western Pennsylvania.

		Name of bed	Thickness of Coal	Distance to next lower coal in feet.
Permian Series	Greene Formation	Windy Gap	?	*
		Nineveh	18 to 20 in.	110—140
		Hostetter	12 to 15 in.	30— 40
		Dunkard	12 to 18 in.	125
		Tenmile (Sparta)	18 inches,	60
		Upper Washington	0 to 14 in. (Locally 2 ft. 1 in.)	
	Washington Formation	Upper Wash. limestone at top		70
		Jollytown	0 to 3 ft.	80
		Washington "A"	0 to 5 ft.	70— 80
		Washington	0 to 10 ft.	12— 15
		Little Washington	0 to 12 in.	30
		Waynesburg "B"	12 to 24 in.	40
		Waynesburg "A"	0 to 4 ft.	50— 80
Pennsylvanian Series	Monongahela Formation	Waynesburg	0 to 10½ ft.	20— 45
		Little Waynesburg	0 to 12 in.	60— 70
		Uniontown	0 to 3 ft.	115—160
		Sewickley (Mapletown, Meigs Creek)	0 to 6 ft.	40— 80
		Redstone (Pomeroy bed of Ohio)	0 to 6½ ft.	30— 80
		Pittsburgh	4 to 16 ft.	25— 60
	Conemaugh Formation	Little Pittsburgh	12 to 24 in.	75—100
		Little Clarksburg (Bavington?)	0 to 24 in.	85
		Wellersburg	0 to 24 in.	80
		Duquesne (Elk Lick, Barton)	0 to 36 in.	25— 35
		Ames limestone		
		Harlem (Friedensville, Crinoidal, Platt)	0 to 4 ft.	60— 90
		Bakerstown	0 to 7½ ft.	70—170
		Brush Creek (Gallitzin, Masontown, Mason, Farmington)	0 to 4 ft.	40— 50
		Mahoning	0 to 5 ft.	40— 70
	Allegheny Formation	Upper Freeport ("E", Lemon, Cap, Coke Yard)	0 to 9 ft.	20— 65
		Lower Freeport ("D", Moshannon, Limestone)	0 to 16 ft.	35— 80
		Upper Kittanning ("C′", Pot Cannel, Cement)	0 to 15 ft.	10— 30
		Gorman (local)	0 to 4 ft.	10— 30
		Middle Kittanning ("C")	0 to 6 ft.	15— 30
		Darlington (Bens Creek, Lower Kittanning Rider)	0 to 4 ft.	15— 40
		Lower Kittanning ("B", Miller, White Ash)	0 to 6 ft.	3— 20
		Lower Kittanning (under bench)	0 to 3 ft.	10— 60
		Vanport limestone		0— 30
		Scrubgrass (Upper Clarion)	0 to 3 ft.	0— 35
		Clarion (A′)	0 to 7 ft.	20— 30
		Craigsville (local)	0 to 3½ ft.	0 to 25
		Brookville (A)	0 to 8 ft.	10— 30
	Pottsville Formation.	Upper Mercer (Mt. Savage)	0 to 4 ft.	40— 70
		Lower Mercer	0 to 4 ft.	5— 20
		Quakertown	0 to 4 ft.	50—100
		Sharon	0 to 5 ft.	50—150

*1050 ft. above Waynesburg coal.

The horizons listed above naturally vary greatly in importance. Some of them contain persistent coal beds of remarkably uniform thickness over wide areas as, for example, the Pittsburgh bed. In the case of others, the workable beds are restricted to comparatively small areas, while in others the coal has never been found to be of minable thickness. Along some of the horizons beds of cannel coal and carbonaceous shale are apt to be found and frequently, although very little or no coal may be present, its place is taken by a considerable thickness of carbonaceous shale. One of the objects of this investigation was to determine whether any of these shales are likely to offer possible sources of oil in the future.

Geologic Structure.

Over the greater part of western Pennsylvania the strata have been only slightly disturbed from their original horizontal position. The uplift has been largely a vertical one. In many places, particularly in the extreme western portion of the State, in a single outcrop the formations appear to be horizontal. When levels are run along a particular bed, however, over a considerable area, it is soon discovered that the surface made by such a stratum is a gently rolling one, consisting of low broad ridges, or anticlines, and equally broad shallow valleys or synclines.

In the extreme western part of the State these anticlines and synclines are the least accentuated. Going eastward they become narrower and closer together, also the anticlines rise higher and the synclines are deeper, thereby increasing the dip of the strata on their flanks. In the southwestern part of the State the anticlines and synclines trend N. 20-25° E. Going northward they tend to swing more toward the east until in the northern part of the State the trend is N. 45-60° E. This condition prevails over the part of Pennsylvania included in the Appalachian plateau which extends as far eastward as the Allegheny Front in eastern Somerset and Cambria and western Center counties. East of the Allegheny Front the folding has been much more pronounced.

It has been found that the degree of de-volitilization which has taken place in the coals is closely related to the amount of deformation which the strata have undergone. Of course numerous exceptions occur, as frequently in the same district two different beds of coal show appreciable differences in their carbon ratios and variations even in the same bed may occur within comparatively short distances. The cannel coals, as a rule, run higher in volatile matter than the ordinary coals associated with them.

Notes on Deposits Sampled and Tested.

(Arranged by Counties)

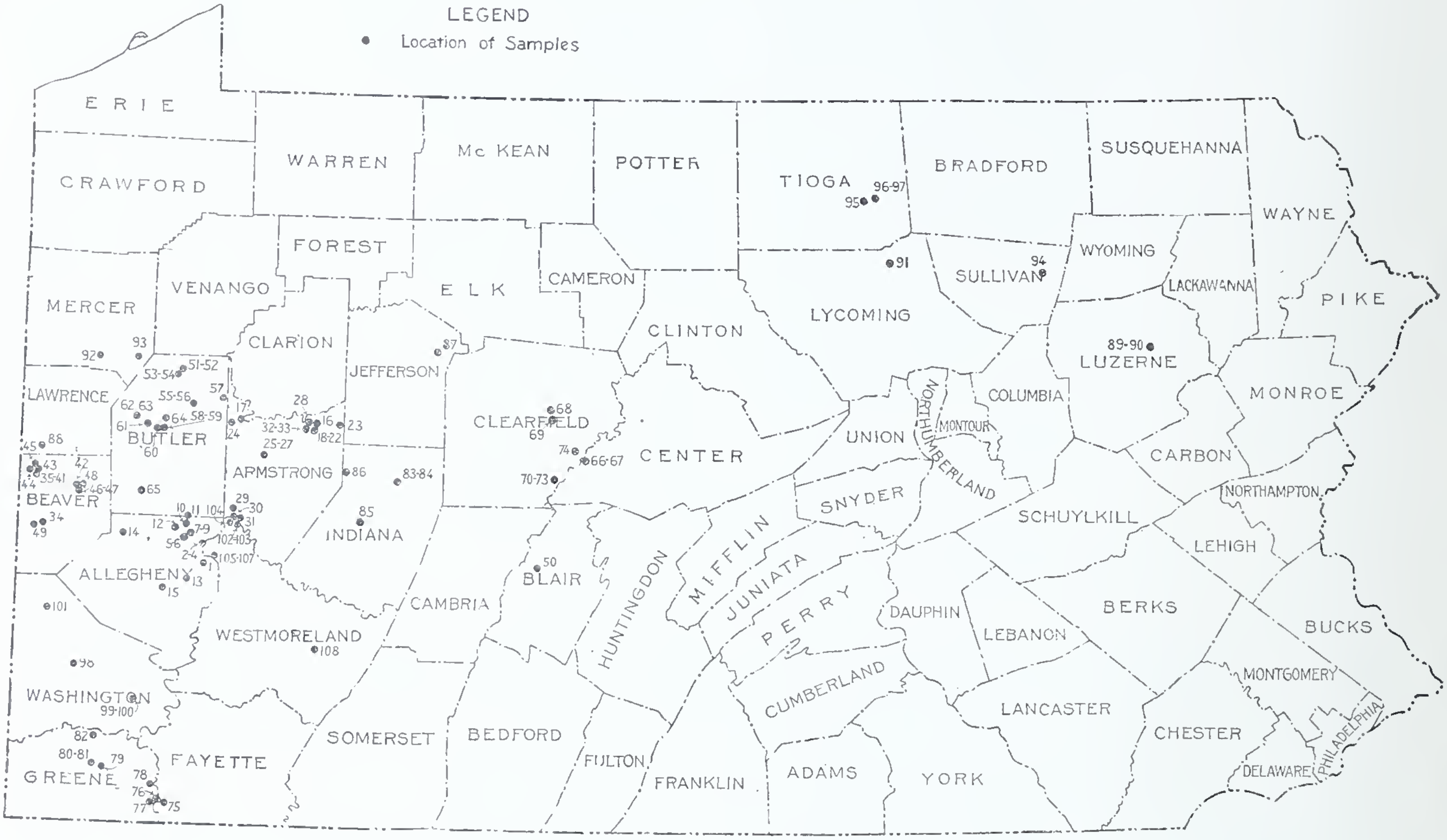

FIGURE 4. Map of Pennsylvania, showing location of samples tested.

The accompanying map (fig. 4) shows the localities where samples of coal or carbonaceous shale were collected which have been tested in the laboratory in connection with the present investigation. The numbers on the map refer to the samples.

Allegheny County.

The lowest strata exposed in Allegheny County belong to the Allegheny formation and the highest, to the Washington. All of the intervening horizons, therefore, show at the surface at some place in the county. The beds dip gently toward the southwest so that the lower formations come to the surface in the northeastern part of the county, while the highest ones are found capping the hills in the southwestern portion. This simple structure is modified somewhat by several broad anticlines and synclines having a northeast trend across the county.

The coals of Allegheny County have fixed-carbon percentages, computed on a pure coal basis, ranging from 57 to 63 and are, therefore, of bituminous rank. While some belong to the Belmontite type, most of them come under the Pittsite type of Ashley's classification.[1] Cannel coals and shales found associated with them can be expected to yield a fair quantity of oil if their ash content is not too high.

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[1] Ashley, George H. The origin of Pennsylvania coal. Pennsylvania Bureau of Topographic and Geological Survey Bull. 8, p. 5, 1920.

During the present investigation, samples from three horizons; namely, the Upper Freeport, Duquesne, and Pittsburgh, were tested.

Samples 1 to 12 inclusive were taken from the horizon of the Upper Freeport coal. Over a considerable portion of northeastern Allegheny County, the Upper Freeport coal is remarkably well developed, reaching a maximum thickness of 10 feet. This area is commonly spoken of as the "Thick Freeport" district. In a considerable part of the area it is overlain by a varying thickness of cannel shale. At present, practically no attempt is being made to recover any of this cannel shale. It is left underground. In figure 5 the extent of the cannel shale deposit associated with the Upper Freeport coal has been approximately outlined by means of the broken line. It covers an area of about 48 square miles. At the southeastern end the deposits extend a short distance over into Westmoreland County.

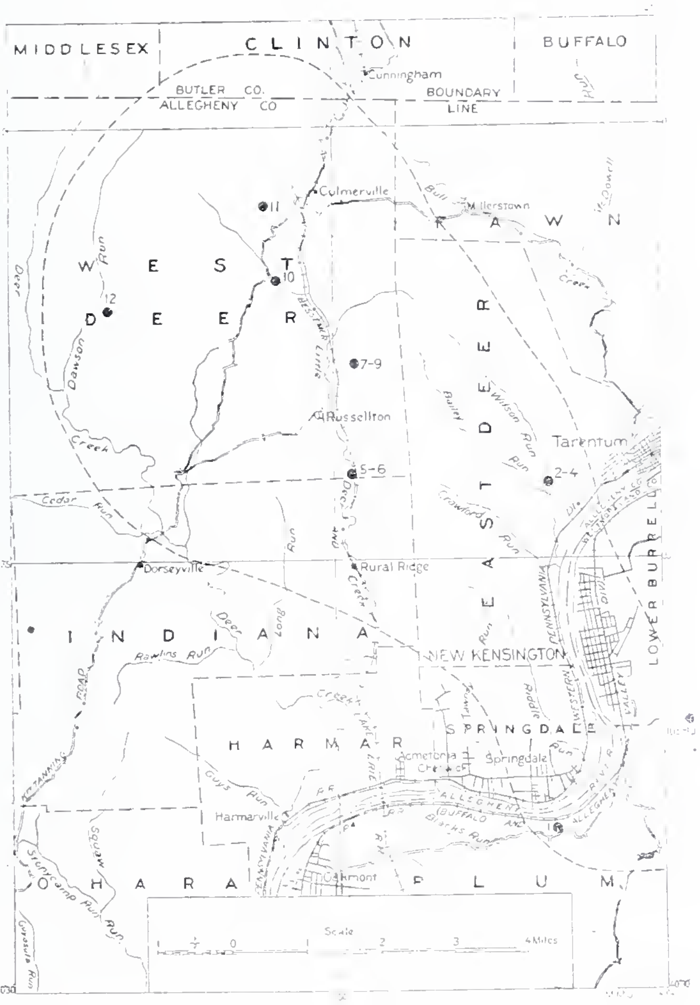

FIGURE 5. Map showing extent of Upper Freeport cannel shale deposits, northern Allegheny County.

At the Oakmont No. 1 mine of the Diamond Coal and Coke Company, at Barking Station, the following composite section of the Upper Freeport coal was measured:—

Section of Upper Freeport coal at Barking Station.

	Ft.	In.
Gray shale roof.		
Cannel shale	1	10
Bituminous coal	2	10
Bony coal		11
Bituminous coal	2	8
Carbonaceous shale		1
Bituminous coal		3
Carbonaceous shale		1
Bituminous coal		6
Clay floor		

Sample No. 1, representing the cannel shale, gave a yield of 25.5 gallons of oil per ton.[1]

At the Creighton mine of the Pittsburgh Plate Glass Company at Creighton, the following composite section was obtained:—

Section of Upper Freeport coal at Creighton.

	Ft.	In.
Shale roof		
Cannel shale	3	4
Bituminous coal	2	8
Bony coal		7
Bituminous coal	3	2
Clay floor		

Sample No. 2, representing the two benches of bituminous coal, gave a yield of 24.8 gallons of low-temperature tar per ton. Sample No. 3, representing the lower 1 foot 4 inches of cannel shale, gave a yield of 29.6 gallons of oil and sample No. 4, representing the upper 2 feet, gave a yield of 13.4 gallons.

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[1] The kind of retort used is indicated in the tables in chapter VII.

At the Bessemer No. 2 mine of the Republic Iron and Steel Company, one mile south of Russellton, the following section was measured along the north entry between west 9 and 10 butt entries to left:—

Section of Upper Freeport coal near Russellton.

	Ft.	In.
Gray shale roof		
Cannel shale	1	7
Bituminous coal	2	10
Bony coal		5
Bituminous coal	3	2
Clay floor		

Sample No. 5, representing the bony coal, gave a yield of 10.9 gallons of low-temperature tar per ton and sample No. 6, representing the cannel shale, 26.4 gallons of oil.

At the No. 1 mine of the Superior Fuel Company, two-thirds of a mile northeast of Russellton, the following composite section was obtained:—

Section of Upper Freeport Coal near Russellton.

	Ft.	In.
Gray shale		
Carbonaceous shale		8
Cannel shale	3	5
Bituminous coal	1	11
Shale		3
Bituminous coal		9
Bony coal		8
Bituminous coal	3	0

Sample No. 7, representing the bony coal, gave a yield of 16.3 gallons of low-temperature tar per ton; sample No. 8, representing the lower 14 inches of cannel shale, produced 34.7 gallons of oil; and sample No. 9, representing the upper 2 feet 3 inches, 17.6 gallons.

At the Benjamin mine of the Ford Collieries, one-third of a mile northwest of Curtisville, the following section was measured near the shaft bottom:

Section of Upper Freeport coal at Curtisville.

	Ft.	In.
Sandstone roof		
Cannel shale	2	3
Bituminous coal	2	7
Bony coal		11
Bituminous coal	3	0
Clay floor		

Sample No. 10, representing the cannel shale, gave a yield of 27.3 gallons of oil per ton.

At the Francis mine of the same company, two-thirds of a mile west of Culmerville, the following section shows along the main air course near the shaft bottom:—

Section of Upper Freeport coal near Culmerville.

	Ft.	In.
Sandstone roof		
Cannel shale	3	6
Bituminous coal	2	3
Bony coal	1	0
Bituminous coal	3	1
Clay floor		

Sample No. 11, representing the cannel shale, gave a yield of 31.4 gallons of oil per ton.

At the Berry mine of the above company, at Bairdford, the bed shows the following development near the shaft bottom:—

Section of Upper Freeport coal at Bairdford.

	Ft.	In.
Sandstone roof		
Cannel shale	2	4
Bituminous coal	2	10
Bony coal		8
Bituminous coal	3	7
Clay floor		

Sample No. 12, representing the cannel shale, produced 30 gallons of oil per ton.

At the No. 3 mine of the Valley Camp Coal Company, along Pucketa Creek in Westmoreland County, one mile east of Parnassus, the following composite section was obtained:—

Section of Upper Freeport coal near Parnassus.

	Ft.	In.
Fine grained sandstone roof		
Cannel shale		10
Bituminous coal		4
Carbonaceous shale		9

Bituminous coal	2	0
Bony coal		6
Bituminous coal	3	6
Shale		½
Bituminous coal		4
Shale		1
Bituminous coal		11
Clay floor		

Sample No. 105, representing the two thick benches of bituminous coal, which are the only ones mined, gave a yield of 23.6 gallons of low-temperature tar per ton. Sample No. 106, representing the bony coal, gave 16.5 gallons and Sample No. 107, representing the cannel shale, gave 39.1 gallons of oil.

The above described deposit of cannel shale is the largest one thus far discovered in Pennsylvania. It underlies approximately 48 square miles of territory. As is shown by the sections given, the thickness of the cannel shale varies considerably from place to place, but it is safe to assume that the average for the entire area will not be less than 2 feet. There are probably present from 125 to 150 million tons of cannel shale that will average 28 gallons of oil to the ton. Unfortunately, the bituminous coal beneath it is rapidly being mined out and the cannel shale is being left in such condition that it will not be accessible at some future time when petroleum prices will have reached a point where it will become profitable to recover the oil content from materials of this character.

Samples 13 and 14 are from the Duquesne horizon. Over most of the Pittsburgh district the Birmingham shale member of the upper portion of the Conemaugh formation has at its base one or more feet of black carbonaceous shale with sometimes a thin bed of bituminous coal beneath it. The name Duquesne has been given to this coal. It corresponds approximately in position to the Elk Lick horizon as found elsewhere in the State.

Along the East Fork of Sandy Creek, about one-half mile above White Ash or Sandy Creek Station on the Wilkinsburg-Verona Electric Line, the Duquesne horizon shows the following development:—

Section of Duquesne bed near White Ash.

	Ft.	In.
Dark gray sandy shale		
Carbonaceous shale	2	3
Bituminous coal		10
Dark gray sandy shale.		

Sample 13, representing the carbonaceous shale, was taken from an outcrop along a country road and was in a badly weathered condition so that it is not representative of this material under cover. It showed a yield of only 4.6 gallons of oil per ton.

Along the Beaver and Pittsburgh road, one-half mile southeast of Bayne in Franklin Township, the Duquesne horizon exhibits the following characteristics:—

Section of Duquesne bed near Bayne.

	Ft.
Gray shale	
Carbonaceous shale	9
Gray shale	8
Bituminous coal	(thickness ?)

The carbonaceous shale is in a badly weathered condition in the outcrop and sample No. 14 represents only the least weathered portions. This showed a yield at the rate of 8.7 gallons of oil per ton.

A thin bed of carbonaceous shale usually overlies the Pittsburgh coal at Pittsburgh. The following section of this bed was measured in the Squirrel Hill district of Pittsburgh in a cut along Aylesboro Avenue, near Murray Avenue:—

Section of Pittsburgh bed in Pittsburgh.

		Ft.	In.
Roof coal (not mined)	Gray sandy shale		
	Carbonaceous shale .		10
	Bituminous coal ...		7½
	Carbonaceous shale .		2
	Bituminous coal		5
	Clay		2
	Bituminous coal		7
	Gray shale		5
	Bituminous coal		2
	Gray shale	1	1
	Bituminous coal		11½
	Carbonaceous shale .		1½
	Coal		10½
	Clay (drawn slate) ..		9½
Coal mined	Bituminous coal	3	6
	Shale		½
	Bituminous coal	1	9½
	Clay		

Sample 15, representing the carbonaceous shale at the top, produced at the rate of 6.5 gallons of oil per ton.

Armstrong County.

The strata cropping out in Armstrong County belong to the Mississippian and Pennsylvanian series, the Pocono, Pottsville, Allegheny, Conemaugh, and Monogahela formations being represented. During the uplift at the close of the Permian period, the strata were warped into gentle folds with northeasterly trending axes, which, on the whole, have a gentle pitch toward the southwest so that, just as in Allegheny County, remnants of the higher beds remain only in the southern part of the county.

The coals of Armstrong County have fixed-carbon percentages, computed on a pure coal basis, ranging from 56 to 63 and are, therefore, of bituminous rank, ranging from Belmontite to Pittsite, according to Ashley's classification, with the latter type predominating.

During the present investigation, samples from the Lower, Middle, and Upper Kittanning and the Lower and Upper Freeport horizons were tested.

The Lower Kittanning is one of the most important coal beds of the county. At the No. 7 mine of the Pine Run Coal Company, one mile south of New Bethlehem, in Mahoning Township, it has the following thickness:—

Section of Lower Kittanning bed near New Bethlehem.

	Ft.	In.
Dark shale roof		
Bony coal		7
Bituminous coal	2	4
Shale floor		

Sample No. 16 of the bituminous coal obtained at this locality, produced at the rate of 22 gallons of low-temperature tar per ton.

Along Harts Run, in Bradys Bend Township, the Middle Kittanning coal is overlain by cannel shale. The following section was measured at the country bank of Christman and Dewey, near Lacy's Store:—

Section of Middle Kittanning bed near Lacy's Store.

	Ft.	In.
Carbonaceous shale		
Cannel shale	1	2
Bituminous coal	5	3
Shale floor		

Sample No. 17, of the cannel shale, gave a yield at the rate of 28 gallons of oil per ton. The cannel shale appears to be a local development, probably not more than 50 acres.

Along most of the Upper Kittanning horizon, where it is exposed in Armstrong County, from a few inches up to three feet of bituminous coal are present, but the bed exhibits extreme irregularity. The bed is 5 feet thick in small areas. Cannel coal has been found at this horizon in a channel-like deposit, extending from a point about two miles southwest of South Bethlehem in an easterly direction for about 6.7 miles to a point about three-fourths of a mile northeast of McWilliams.

The extent of the cannel coal deposit at this horizon in northern Armstrong County is shown on figure 6. Nearly one-half of the original deposit has been removed by erosion. The black areas on the map show those portions of the channel that have either been mined out or are being mined at the present time. The dotted areas show virgin ground, and the blank spaces along the course represent valleys cut below the coal.

The maximum width of the channel over which coal of minable thickness has been found is approximately 800 feet. The cannel coal has its greatest development along the center line of the channel and thins comparatively rapidly on either side. The bituminous coal, on the other hand, which immediately underlies the cannel, maintains a more nearly uniform thickness over the entire area. Considerable variations in thickness of the cannel coal also occur along the center line of the channel.

The cannel coal is at present being mined at Bostonia, near the head of the small run entering Red Bank Creek just below South Bethlehem. Mine No. 9, of the Pine Run Coal Company, is located in this deposit on the west side of the run. In 1918, the main entry had been driven to the west as far as the next run shown on the map, and the rooms on either side had practically been worked out. The intention of the company, therefore, was to temporarily close the mine until the Upper and Lower Freeport coals above are mined before attempting to take out the pillars. In the meantime, the continuation of the channel on the

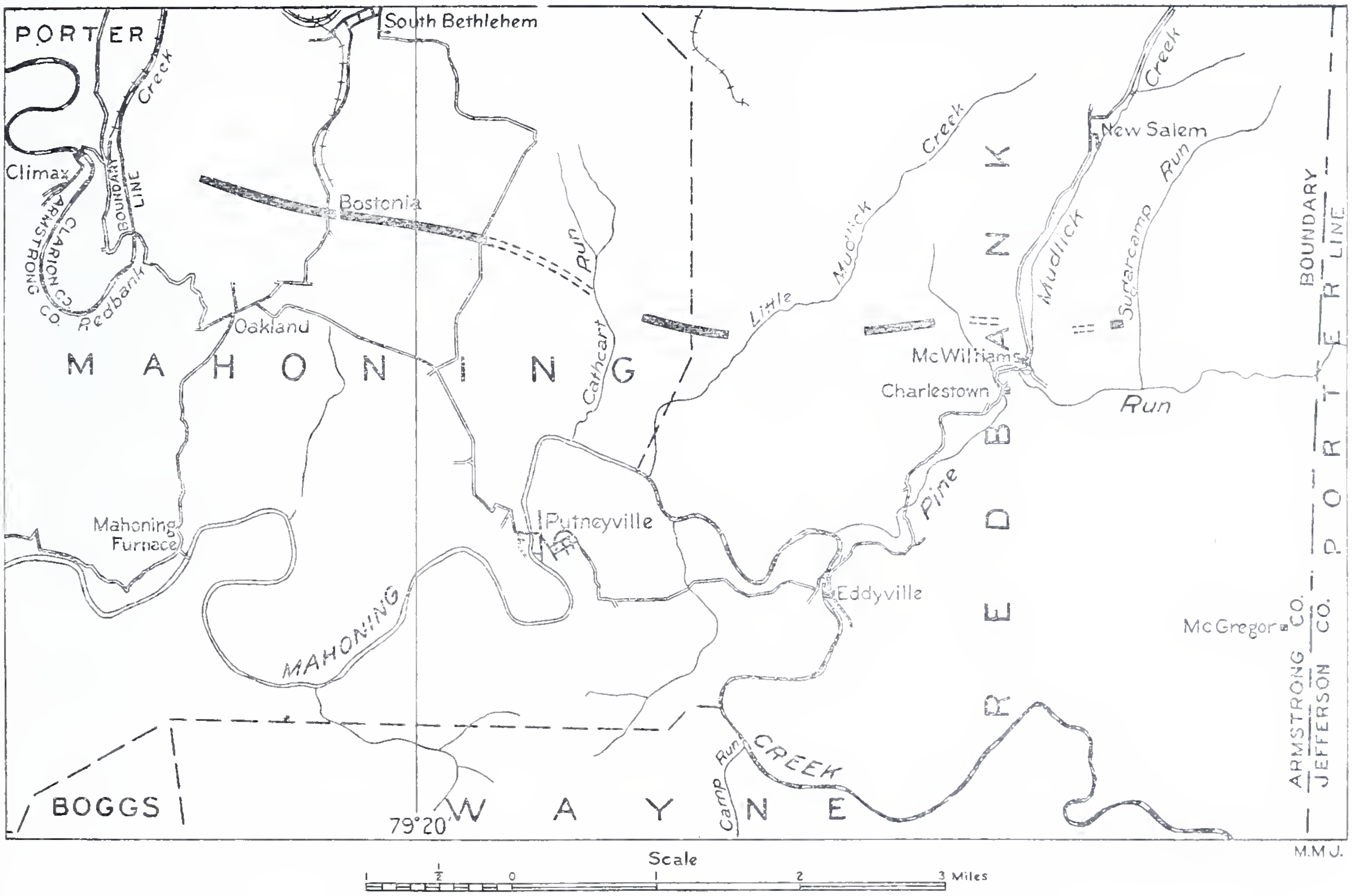


FIGURE 6. Map showing extent of Upper Kittanning cannel coal deposit, northern Armstrong County.

opposite side of the valley to the west, between it and Red Bank Creek, was being sought by means of a diamond drill. The old No. 8 mine in this deposit, on the east side of the run at Bostonia, was being drained and put in shape so that mining could be continued in the virgin ground, shown on the map toward the east.

A cross-section of the channel in the No. 9 mine is shown in figure 7. This was measured about one-third of a mile west from the mouth of the mine. Section 1 of the same figure shows the thickness of the coal near the northern margin of the channel, and sections 2 and 3 are representative of the deposit near the center of the channel at this point. Sections 1 and 2 were measured in room 24 on the north side of the main entry, and section 3 was obtained in room 27 on the south side. The thicknesses developed in these sections were as follows:—

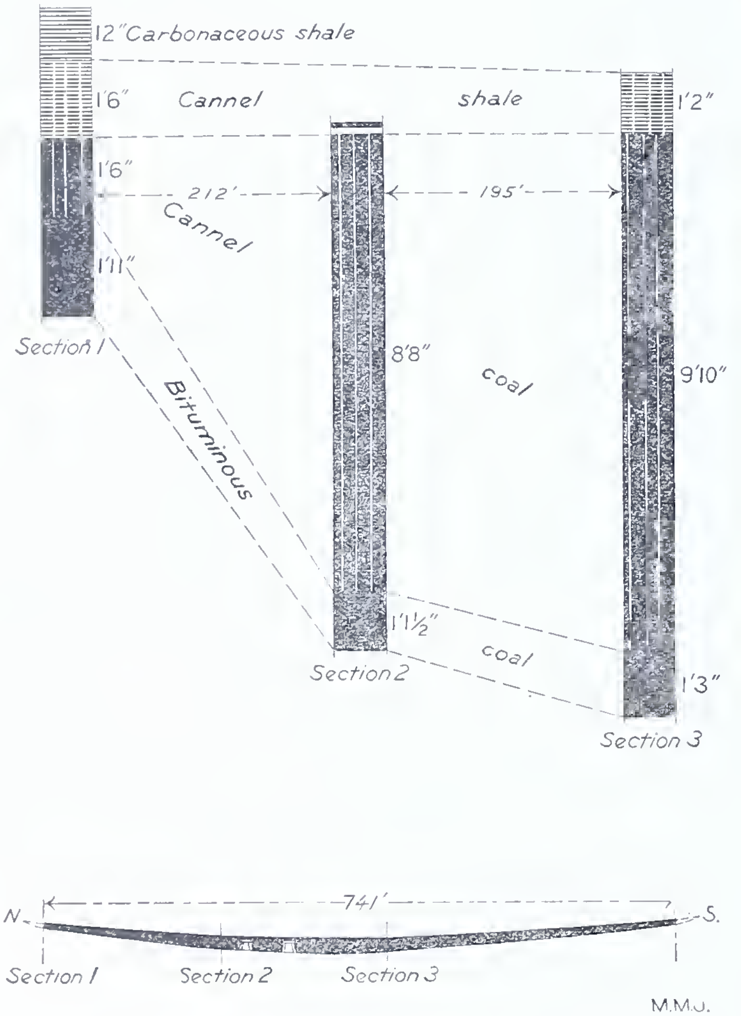


FIGURE 7. Three sections of Upper Kittanning bed and cross-section of deposit as developed in the No. 9 mine of the Pine Run Coal Company at Bostonia, Armstrong County.

Sections of Upper Kittanning bed near Bostonia.

	Section 1	Section 2	Section 3
Carbonaceous shale	1 ft. 0 in.	not measured	not measured
Cannel shale	1 ft. 0 in.	not measured	1 ft. 2 in.
Cannel coal	1 ft. 6 in.	8 ft. 8 in.	9 ft. 10 in.
Bituminous coal	1 ft. 11 in.	1 ft. 1½ in.	1 ft. 3 in.

Sections 4 and 5 were measured in room 72 on the north side of the main entry near its western extremity. The former was near the northern margin of the channel and the latter was near the center, the distance between the two being 507 feet. The sections are as follows:—

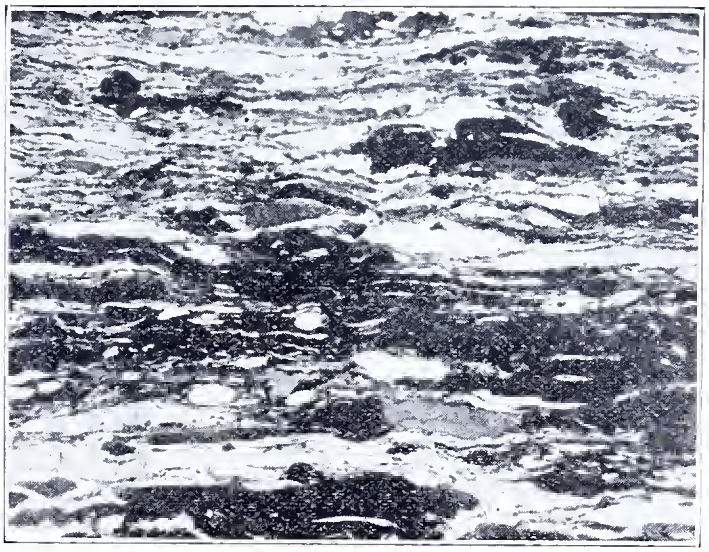
	Section 4	Section 5	Section 6
Gray shale roof.			
Cannel coal	1 ft. 0 in.	3 ft. 6 in.	
Cannel shale	0 ft. 9 in.	1 ft. 2 in.	not measured
Cannel coal	3 ft. 0 in.	5 ft. 6 in.	8 ft. 3 in.
Bituminous coal	1 ft. 11½ in.	2 ft. 4 in.	2 ft. 1 in.
Dark shale floor.			

Section 6, was obtained in room 33 on the south side of the main entry.

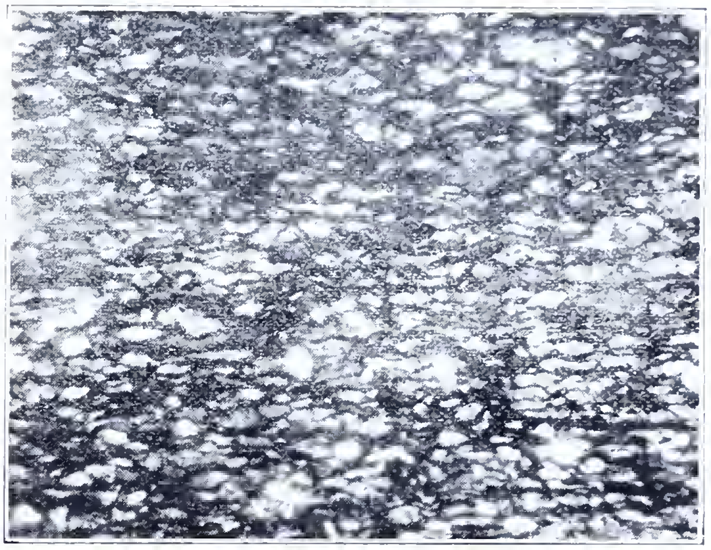
A considerable portion of the cannel coal in this deposit has a "curly" or "bird's eye" structure.

Sample No. 18, representative of the bituminous coal as developed in section 6, showed a yield of 26.1 gallons of low-temperature tar per ton. Sample No. 19, of the cannel coal from the same section, produced at the rate of 32.9 gallons of oil per ton. Sample No. 20, of the "curly" or "bird's eye" cannel coal, obtained in room 38, gave 34.6 gallons per ton; while sample No. 21, of the cannel shale from section 4, gave 22.3 gallons; and sample No. 22, of the carbonaceous shale from room 38, gave 7.8 gallons.

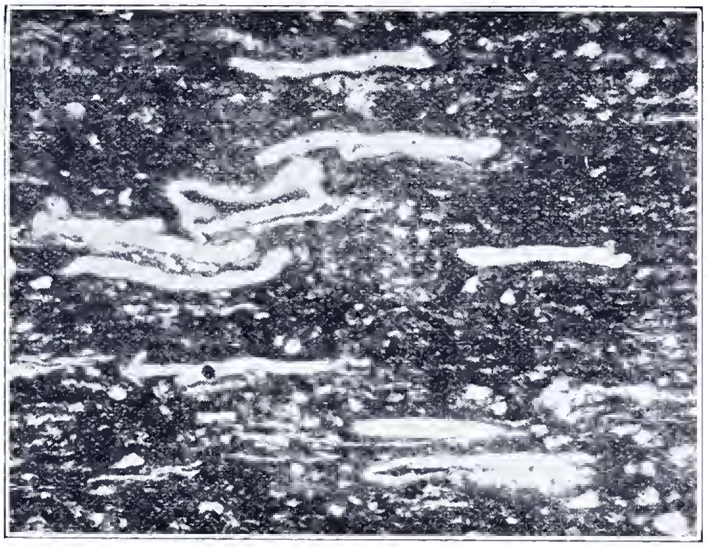
Cannel coal was also mined formerly on the east side of Cathcart Run in mine No. 1 of the Pine Run Coal Company and on the east side of Little Mudlick Creek in mine No. 3 of the same company, but both of these mines are now worked out and abandoned. Some cannel coal was also taken out years ago on the old Jacob Schiech farm, now the G. P. Gruver farm, northeast of McWilliams on Sugar Camp Run.



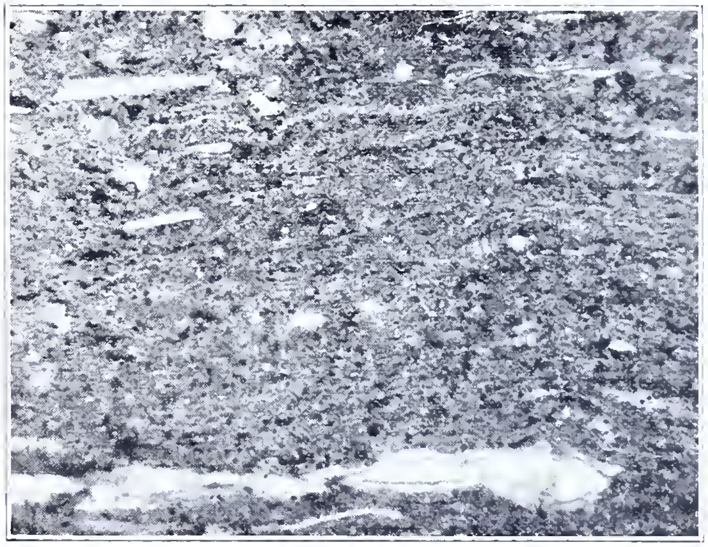
A. Photomicrograph of cannel coal, probably Upper Kittanning horizon, country bank of G. W. Currie, two miles north of Nealeys, Pa. A typical humic cannel coal containing almost no spore remains. Magnified 200 times. (Courtesy R. Thiessen.)



B. Photomicrograph of cannel shale, Lower Freeport horizon, from outcrop three-fourths of a mile southeast of Kiskiminitas Junction, Pa. The true nature of the organism which formed the bodies characteristic of this shale is not yet known. Magnified 200 times. (Courtesy of R. Thiessen).



C. Photomicrograph of oil shale. Chattanooga, Upper Devonian horizon, Taylor County, Ky. A typical spore shale. Magnified 200 times. (Courtesy R. Thiessen).



D. Photomicrograph of oil shale, from Green River formation (Eocene), Soldiers Summit, Utah. Magnified 200 times. Courtesy R. Thiessen).

A. Mouth of Paragon Coal and Coke Company's drift at Cannelton, Pa.

B. Cars of cannel coal at tipple of same company.

According to Ashley,[1] who visited this locality in 1914, the cannel coal in the Pine Run No. 1 mine on Cathcart Run occurred in two benches, the upper from less than three to more than five feet thick and the lower from six inches to seven feet, separated by twelve to twenty inches of "mixed" coal, all underlain by two feet or more of bituminous coal. The "mixed" coal had six inches of bituminous at the bottom and the rest was "curly" cannel with streaks of bituminous. Both the cannel and bituminous coal were irregular, for as the cannel thinned, the bituminous coal thickened, reaching five feet at the back of the mine.

At the Pine Run No. 3 mine on Mudlick Creek, the cannel coal was four to eight feet thick, averaging about six, and was overlain in most places by bituminous coal of the maximum thickness of two feet. In places a little bituminous coal was found under the cannel. The cannel coal ran out in entries to the north, but held its thickness in those to the east. A new mine at that time, opened south of No. 3, but now also abandoned, appeared to be in a branch of the main channel for the cannel coal in it thinned to the east, but held up to seven feet towards the south.

On the G. P. Gruver farm, northeast of McWilliams, the thickness of cannel coal is greatly reduced. Platt[2] gives the following section:—

Section of Upper Kittanning bed near McWilliams.

	Ft.	In.
Shale		
Bituminous coal	3	
Cannel coal	2	6
Bituminous coal	1	
Shale		

In an old opening on this farm the writer measured six feet one inch of bituminous coal, with an 8-inch bench of cannel coal in its lower portion. Sample 23, representative of the latter, yielded at the rate of 30.7 gallons of oil per ton.

The entire tonnage of minable cannel and bituminous coal present originally in those portions of the Upper Kittanning channel deposit of northern Armstrong County, described above, which escaped erosion, was probably not much in excess of 4,000,000 tons.

In Bradys Bend Township, near the head of Holder Run about one-third of a mile north of Somerville, another local development of cannel shale occurs in association with the Upper Kittanning coal. It is not exposed at present and the old mine workings are inaccessible so that the only data available on this deposit is that given by Platt, who describes the occurrence as follows:—"At the Ganner mine in the ravine of Holder's Run the bed is 2 feet thick at the outcrop, increasing within a short distance to 5 feet, all bituminous coal of a fairly good quality. The floor of the seam then rapidly descends at an angle of 10 degrees to a depth of 7 feet, the roof meanwhile remaining horizontal; the interval between is gradually occupied by a mass of impure cannel shale of a dull lustre, and having a conchoidal fracture."[3] Sample No. 24 was obtained by the writer in 1920 from the dump of the old Ganner mine, and is probably fairly representative of the average character of the cannel shale, except that it has been exposed to the weather for many years. It showed a yield of 34.8 gallons of oil per ton.

In East Franklin Township, along a branch of Limestone Run, about one and one-third miles south of Adrian, a considerable thickness of carbonaceous shale and cannel shale occurs associated with the Upper Kittanning coal. The following two sections were obtained along the banks of the stream within a distance of several hundred yards:—

Sections of Upper Kittanning bed near Adrian.

	Section 1	Section 2
Carbonaceous shale	4 ft. 10 in.	9 ft. 6 in.
Gray shale	1 ft. 4 in.	1 ft. 4 in.
Bituminous coal	2 ft. 3 in.	1 ft. 9 in.
Cannel shale	1 ft. 6 in.	(?)

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1. Ashley, George H., Cannel coal in the United States. U. S. Geol. Survey Bull. 659, pp. 60-61, 1918.
2. Platt, W. G. Report of Progress in Armstrong County, Penn. Second Geol. Survey, H 5 pp. 181-182, 1879.
3. Platt, W. G. op. cit. p. 222.

Unfortunately, the outcrop material was pretty badly weathered so that it was impossible to obtain fresh samples. Sample No. 25, of the lower seven feet of the carbonaceous shale exposed in section 2, the one farthest upstream, gave a yield at the rate of 3.4 gallons of oil per ton. Sample No. 26, of the carbonaceous shale from section 1, gave 6.0 gallons of oil per ton, and sample No. 27, of the cannel shale from the same section, gave 18.6 gallons.

In a prospect opening of the Pine Run Coal Company, one and one-quarter miles south of New Bethlehem in Mahoning Township, near Bostonia, the Lower Freeport coal shows the following development:—

Section of Lower Freeport coal near Bostonia.

	Ft.	In.
Dark sandy shale roof		
Bituminous coal	2	1
Bony coal		1
Bituminous coal		3
Shale floor		

Sample No. 28, representative of the bituminous coal, gave a yield at the rate of 23.4 gallons of low-temperature tar per ton.

In the vicinity of Freeport, a bed of cannel shale, covering approximately 2.15 square miles of territory, occurs associated with the Lower Freeport coal. This deposit is of considerable historical interest on account of the flourishing coal oil industry which it supported during the period just prior to the development of the petroleum industry in the United States. At present, the old mine workings are inaccessible and information in regard to the extent and character of the deposit can only be obtained from a few scattered outcrops and observations on the nature of the material found on the old mine dumps.

The outcrop of the Lower Freeport in the vicinity of Freeport and Kiskiminitas Junction is shown by a solid black line on figure 8. The proable horizontal extent of the cannel shale deposit is indicated by the area enclosed within the broken line, and the points at which samples were obtained are marked by black dots and numbers corresponding to those assigned to the samples.

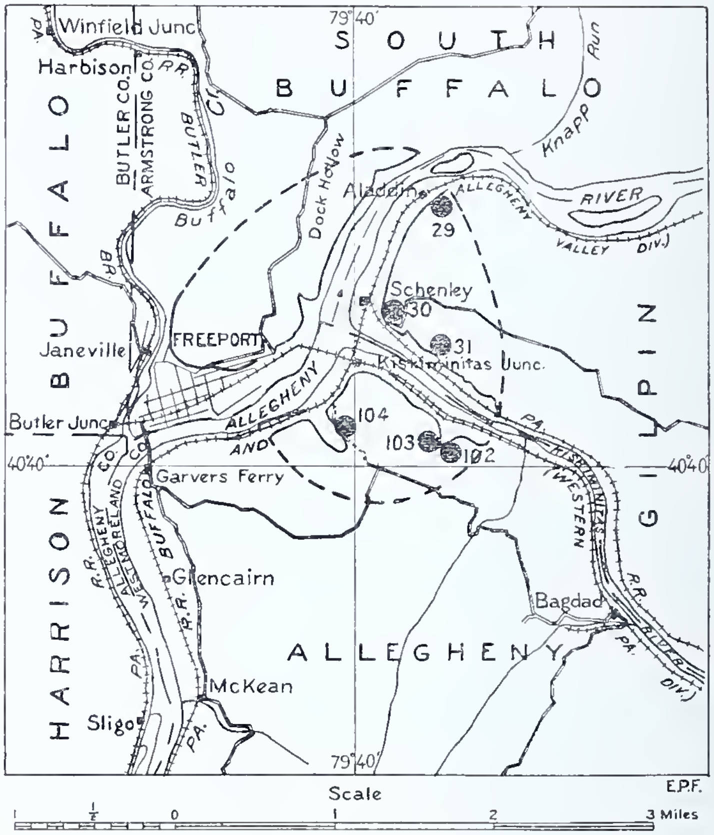

FIGURE 8. Map showing extent of Lower Freeport cannel shale deposit in the vicinity of Kiskiminitas Junction. Pa.

Along the road just above Schenley at an approximate elevation of 860 feet, the following section was measured:—

Section at Schenley.

	Ft.	In.
Dark gray shale		
Upper Freeport coal	4	3
Clay	3	
Limestone	2	
Covered	26	8
Cannel shale	3	4
Shale	6	8
Lower Freeport coal only upper part exposed.		

The cannel shale also crops out in Westmoreland County along a small run flowing north into Kiskiminitas River, three-fourths of a mile southeast of Kiskiminitas Junction. Along the east side of this run the following section was obtained:—

Section near Kiskiminitas Junction.

	Ft.	In.
Sandstone roof		
Upper Freeport coal	3	6
Gray clay	30	
Platy sandstone		
Covered		
Carbonaceous shale	2	
Cannel shale	2	9
Dark gray shale	7	
Lower Freeport coal	2	8
Gray shale		

On the opposite side of the run the cannel shale measures 2 feet 10 inches. Along the steep bluff on the east side of Buffalo Creek, just north of Freeport, the interval between the Upper Freeport coal and the cannel shale is 64 feet. The cannel shale at this point is 3 feet thick.

Sample No. 29 was obtained from the dump of the old Aladdin Company's mine at Aladdin. It showed a yield of oil at the rate of 35.4 gallons per ton. Sample 30 came from the outcrop at Schenley described above and was deeply weathered. It gave 23.9 gallons per ton. Sample No. 31 was procured from the dump of the old North American Company's mine, one-half mile southeast of Schenley along the north bank of Kiskiminitas River. It produced at the rate of 34.5 gallons of oil per ton. The other three samples were taken on the south sides of the Allegheny and Kiskiminitas Rivers in Westmoreland County. Sample No. 102 came from the outcrop described above which occurs along the small run flowing northward into Kiskiminitas River, three-fourths of a mile southeast of Kiskiminitas Junction. It gave 37.7 gallons of oil per ton. Sample No. 103 came from the opposite side of this same run and yielded 38.5 gallons. Sample No. 104 was obtained from the dump of the old Lucesco Company's mine along Lucesco Hollow, one-half mile south of Kiskiminitas Junction. It produced at the rate of 36.3 gallons per ton.

Approximately 2.15 square miles in the vicinity of Kiskiminitas Junction are underlain by the cannel shale deposit described above. In thickness the shale probably averages from 2½ to 3 feet over this entire area so that there were present originally in the neighborhood of 7 to 8 million tons of cannel shale. Mining operations in the past apparently have been confined entirely to that portion lying east of Allegheny River, so that nearly 50 per cent of the area still represents virgin ground.

The Upper Freeport coal has the following development in the Pine Run Coal Company's No. 10 mine, 1½ mines south of New Bethlehem at the head of the small run entering Red Bank Creek from the south just below the town:—

Section of Upper Freeport coal south of New Bethlehem.

	Ft.	In.
Shale roof		
Cannel shale		6
Bony coal	1	1½
Bituminous coal	3	9
Clay floor		

Sample No. 32 of the bituminous coal produced at the rate of 25.8 gallons of low-temperature tar per ton. Sample 33 of the cannel shale gave a yield of 18.3 gallons of oil per ton.

Beaver County.

The geological age of the formations appearing at the surface in Beaver county ranges from Pottsville to Monongahela. The lowest strata, the Pottsville, appear only along Beaver River and its tributaries in the northern part of the county, while a few small remnants of the Monongahela formation appear on the tops of the hills in the southern part. Over most of Beaver county the outcropping formations belong to the Allegheny and Conemaugh series.

The coals of Beaver County range from 56 to 61 in fixed-carbon percentages, computed on a pure coal basis. They are of bituminous rank, belonging to the Belmontite and Pittsite types of Ashley's classification.

Samples from the Lower and Upper Kittanning, Upper Freeport, Mahoning, Brush Creek, and Bakerstown horizons were tested in the laboratory.

The Lower Kittanning coal was examined in the country bank of William Fairweather, at Industry, where there is 3 feet 2 inches of coal between a dark gray shale roof, and floor. Sample 34 of the bituminous coal gave a yield of low-temperature tar at the rate of 24.6 gallons per ton.

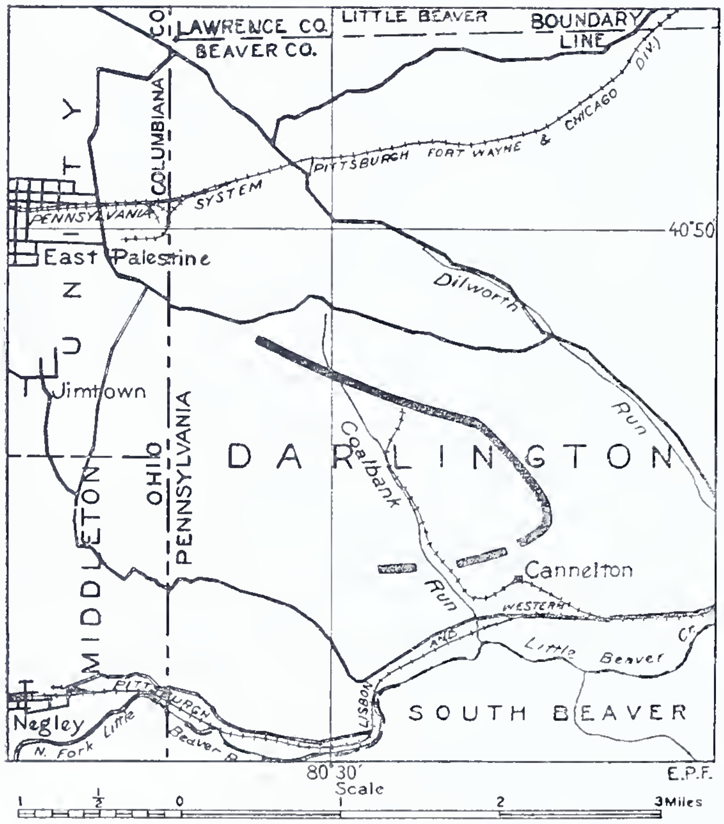

FIGURE 9. Map showing extent of Upper Kittanning cannel coal deposit at Cannelton, Beaver County, Pa.

In the northwest corner of Beaver County is located the famous Cannelton bed of cannel coal. This deposit appears to occupy an old channel which had the shape of a huge ox-bow (fig. 9). The channel has a total length of nearly 3½ miles and a width of only 600 feet. It occurs at the Upper Kittanning horizon. The writer measured the following section along the run and adjoining hills north of Cannelton:—

Section at Cannelton.

		Ft.	In
	Mahoning coal	2	8
	Clay	2	
	Covered	38	
Upper Freeport coal	Shale roof		
	Coal	4	
	Clay		1½
	Coal		2
	Shale floor		
	Covered	114	
	Upper Kittanning Cannel bed	9	
	Covered	50	
	Lower Kittanning coal	1	7½
	Fire clay	6	

The existence of the Cannelton deposit, according to I. F. Mansfield, was known to the Indians at least as early as 1750, and from them the white men first heard of it. Mining on a small scale was commenced early in the last century but it was not until about 1855, when the cannel coal and the richer portions of the cannel shale associated with it commenced to be sought for the manufacture of oil, that extensive operations were undertaken. From that time mining was carried on practically continuously until about 1900 when the thicker portions of the deposit were nearly exhausted.

During 1918, the Wistar Coal Corporation of Buffalo, New York was doing a little development work on the east side of the run north of Cannelton. During the previous operations, only the thicker portions of the channel were mined and no systematic attempt was made to extract the pillar coal. The Wistar Coal Corporation, therefore, was driving two drifts, one on the northwest and the other on the southeast side of the channel, which has a north easterly trend at this place, in order to determine how much coal was still available along the sides of the channel and how much of the pillar coal left during previous operations could be recovered. Another company, the Beaver Cannel Coal Company, was operating a small mine at the extreme northwest end of the channel, near East Palestine. In 1921, the Paragon Coal and Coke Company, the successor of the Wistar Coal Corporation, was taking out a small quantity of cannel and bituminous coal from the latter company's north drift. Plate V A shows the mouth of this drift, and B the company's tipple.

According to White,[1] who visited the locality in 1876, and I. F. Mansfield, who formerly mined the deposit on an extensive scale, the cannel coal was 12 feet thick along the middle of the channel, although in most places it did not exceed 7 feet. A good thickness was maintained for a width of about 300 feet, on either side of which the coal thinned rapidly. The channel has a maximum width of about 600 feet. Overlying the cannel coal along the middle of the channel there are as much as six feet of cannel shale. This also thins comparatively rapidly on either side, but probably extends over a greater width than the cannel coal. Underlying the cannel coal is a thin bench of bituminous coal. A little bituminous coal also occurs interbedded with the cannel in places. At the extreme northwest and southwest ends of the channel, the cannel coal and shale disappear entirely and only bituminous coal remains.

Figure 10 shows the position of the openings made by the Wistar Coal Corporation in 1918 with respect to the cannel coal channel. These are on the east side of the small run just north of Cannelton. In 1921, the Paragon Coal and Coke Company was taking out a small tonnage of cannel coal from the north drift which had been extended to a distance of about 1200 feet from the mouth. Figure 10 also gives four sections of the coal bed.

At the extreme northwestern end of the deposit, near East Palestine, Ohio, at the face of the Beaver Cannel Coal Company's main entry, as developed in 1918, there was 2 feet 8½ inches of bituminous coal between roof and floor of dark gray sandy shale.

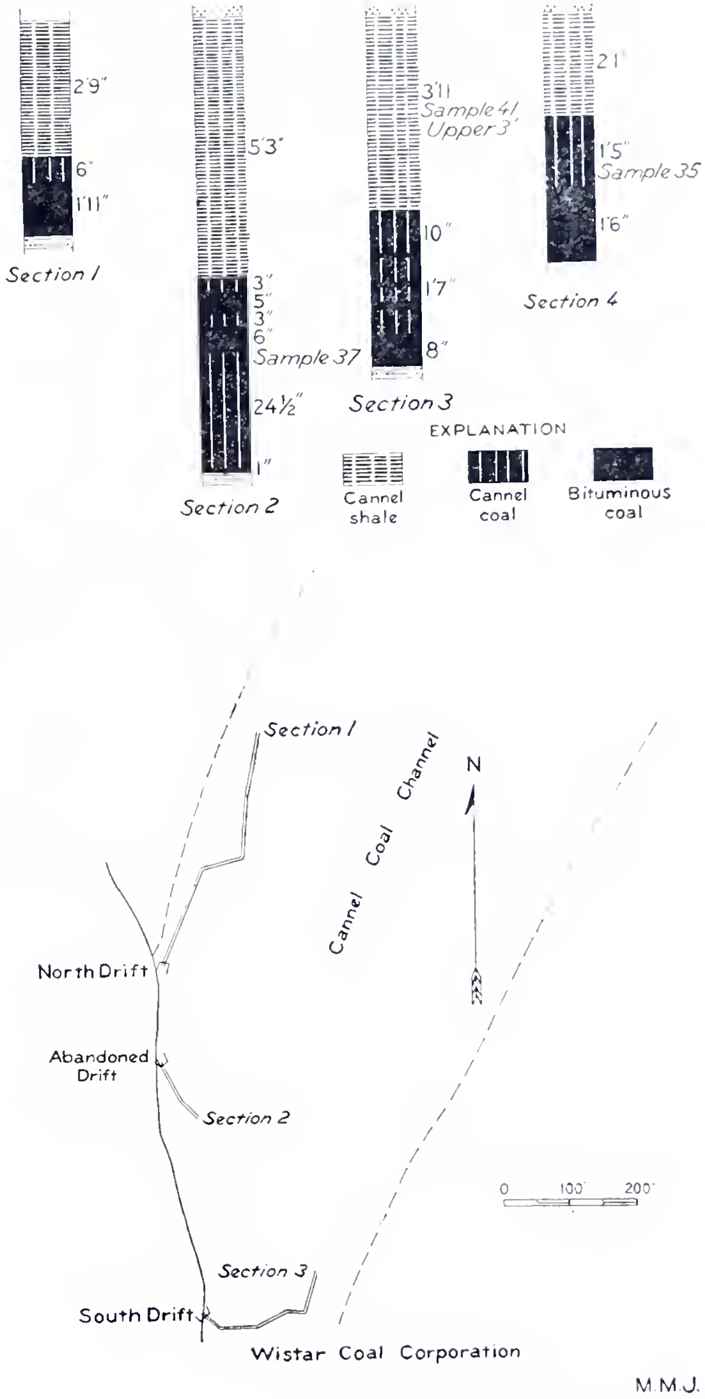

FIGURE 10. Sketch map of Wistar Coal Corporation's drifts at Cannelton, Pa., as developed in 1918, and several sections of the cannel coal.

Sample No. 35, representing the bench of cannel coal encountered in section 4, (fig. 10), gave a yield at the rate of 54.9 gallons of oil per ton.

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[1] White, I. C. Report of Progress in the Beaver River district of the bituminous coal fields of western Pennsylvania, Pennsylvania Second Geol. Survey, Report Q, pp. 233-234, 1878.

Sample No. 36, representing the cannel shale shown in section 1, gave a yield of 44 gallons of oil per ton. Sample No. 37, representing the middle two benches of bituminous coal of section 2. produced at the rate of 34.3 gallons of low-temperature tar per ton. Sample Nos. 38 and 39, two samples taken at different times, of the lower bench of cannel coal shown in section 2, gave yields of 47.3 and 49.4 gallons of oil per ton, respectively. Sample No. 40, of the cannel shale from the same section, produced at the rate of 31.7 gallons of oil per ton; while sample No. 41 of the upper 3 feet of cannel shale shown in section 3, gave a yield of only 15 gallons per ton.

The cannel coal and shale of this deposit yield a relatively high percentage of oil and they were, therefore, very much sought after in the days when the "coal oil" industry flourished in the United States.

The writer estimates that a maximum of about 2 million tons of cannel coal was originally present in the Cannelton deposit and perhaps an equal tonnage of cannel shale. On account of the wasteful methods of mining employed in the early days, probably not more than one-half of the coal was extracted. The rest remains underground along the margins of the channel and in the pillars which were left behind. Most of the cannel shale also remains as only small portions of the very richest shale were extracted during the former operations. On account of the poor condition of the underground workings of the old mines, however, it is extremely doubtful whether in the future it will be possibly to extract profitably any very great percentage of the cannel coal and shale still remaining.

In Daugherty Township, near the head of the small run emptying into Beaver River opposite Beaver Falls, a bony coal occurs at what is probably the Upper Kittanning horizon. The following section was obtained along this run.

Section near Beaver Falls.

		Ft.	In.
	Massive sandstone		
Coal—probably Lower Freeport	Bituminous coal		6
	Bone		2
	Bituminous coal		11
	Shale	27	
	Interval		
	Gray shale		
	Carbonaceous shale ..		4
Coal—probably Upper Kittanning	Bituminous coal		6
	Bone		8
	Bony coal		10
	Bone		7
	Bony coal		3
	Bituminous coal		9
	Sandy shale		
	Interval	77	
	Lower Kittanning coal	1	11
	Fire clay		
	Interval	90	
	Clarion coal	1	3
	Fire clay		

Sample No. 42 of the Upper Kittanning coal, including the bone, from this locality, gave a yield at the rate of 26.5 gallons of oil per ton.

One-half mile north of Cannelton, in Darlington Township, the Upper Freeport coal shows the following development in the Keystone Drilling Company's mine:—

Section of Upper Freeport coal north of Cannelton.

	Ft.	In.
Shale roof		
Bituminous coal	4	
Clay		1½
Bituminous coal		2
Shale floor		

Sample No. 43 of the bituminous coal produced at the rate of 23.2 gallons of low-temperature tar.

One-half mile west of Cannelton, the same bed has the following thickness in the Pittsburgh Cannelton Coal Company's mine:—

Section of Upper Freeport coal west of Cannelton.

	Ft.	In.
Shale roof		
Bituminous coal	1	1½
Carbonaceous shale		½
Bituminous coal	1	1½

Carbonaceous shale		½
Bituminous coal		3½
Shale		1½
Bituminous coal		3
Clay floor	1	8
Limestone	1	8

Sample No. 44 of the bituminous coal gave a yield at the rate of 24.1 gallons of low-temperature tar.

One and one-half miles northwest of Cannelton, in Darlington Township, the Mahoning coal, which lies 38 feet above the Upper Freeport in this locality, is 2 feet 8 inches thick in the Union Clay and Coal Company's mine.

Sample No. 45 of this coal produced at the rate of 27.5 gallons of low-temperature tar per ton.

In northern Daugherty and southern North Sewickley townships, a cannel shale is frequently found associated with the Brush Creek coal. In a country bank on the farm of Elmer E. Plugh, two and one-half miles northeast of New Brighton in northern Daugherty Township, this bed has the following development:—

Section of Brush Creek bed in Daugherty township.

	Ft.	In.
Gray shale		
Carbonaceous shale	1	9
Cannel shale	1	8
Bituminous coal	1	2
Shale		½
Bituminous coal		6
Clay		

Sample No. 46 of the cannel shale was obtained about 100 feet from the mouth of the drift. It gave a yield at the rate of 23.8 gallons of oil per ton. Sample No. 47 of the carbonaceous shale was obtained at the mouth of the drift and hence was considerably weathered. It showed only 5.1 gallons of oil per ton.

In southern North Sewickley Township, in a country bank on the farm of Samuel Longnecker, three and three-fourths miles northeast of New Brighton, the following section shows:—

Section of Brush Creek bed in North Sewickley township.

	Ft.	In.
Carbonaceous shale		
Cannel shale	2	7
Bituminous coal	1	1
Clay		

Sample No. 48 of the cannel shale yielded at the rate of 22 gallons of oil per ton.

The Longnecker farm is joined by the old Graham estate on the north on which the Brush Creek coal was opened at one time, and for which White[1] gives the following section:—

Brush Creek coal	Carbonaceous shale	1 ft.
	Cannel shale	4 ft.
	Bituminous coal	1 ft.

It lies 75 feet above the Freeport coal in this vicinity.

In Greene Township, one mile east of Georgetown along the steep south bank of Ohio River, a cannel coal, probably belonging to the Bakerstown horizon, was at one time mined by J. R. Peters. It lies 100 feet below the Ames limestone The old workings were inaccessible at the time of the writer's visit to the locality in 1920, so that no data could be obtained in regard to it. Stevenson[2] described it as a bed 6 feet thick, with the upper half high in ash. It is undoubtedly purely a local development extending over only a small area. Less than one mile west of this locality, along the Georgetown-Hookstown road, only 30 inches of carbonaceous shale are present at this horizon. Sample No. 49 of the cannel coal was obtained from the dump of the old Peter's mine. It yielded at the rate of 34.5 gallons of oil per ton. According to Stevenson, some oil was manufactured from it before the discovery of petroleum in Pennsylvania.

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[1] White, I. C. op. cit. pp. 36 and 213.

[2] Stevenson, J. J. Report of progress in the Greene and Washington districts of the bituminous coal-fields of Western Pennsylvania. Pennsylvania Second Geol. Survey, Report K, p. 348, 1876.

Blair County.

In and about Altoona, at several places southwest of that town for a distance of twenty miles and along the Pennsylvania Railroad between Altoona and Bellwood, a black carbonaceous shale from 75 to 80 feet thick is well exposed. This shale occurs at the base of the Upper Devonian and has been named the Burket shale by Butts[1] after a suburb of that name, southwest of Altoona, where a good outcrop occurs. The outcrop follows along the base of the Allegheny Front and the strata dip northwest.

The shale is very fissile, cleaving readily into thin plates. It has a black color, due to the carbonaceous matter in it. Sample No. 50 was taken from an excavation for a house foundation in the vicinity of East Altoona. The material was considerably weathered and yielded no oil and only a comparatively small amount of gas. Even under cover, however the yield of oil would probably be very slight if any, on account of the excessive amount of metamorphism which the strata in this vicinity underwent during the period of Appalachian folding at the close of the Permian.

Butler County.

The strata appearing at the surface in Butler County belong to the Pottsville. Allegheny, and Conemaugh formations. The beds on the whole have a gentle dip towards the south, modified only by several small anticlines and synclines which cross the county from northeast to southwest.

The coals carry 55 to 63 per cent fixed-carbon, computed on a pure coal basis, and hence belong to the Belmontite and Pittsite types of Ashley, with the former predominating.

The Brookville coal has been rather extensively mined in northern Butler County along the Hilliard Branch of the Bessemer and Lake Erie Railroad. In the first room off of No. 2 main entry in the Bessemer mine of the Butts Cannel Coal Company, one-half mile northeast of Deegan P. O., the following section was measured:—

Section of Brookville coal near Deegan.

		Ft.	In.
	Shale roof		
Upper Bench	Bituminous coal		3
	Bony coal		1½
	Bituminous coal		2
	Sulphur band		½
	Bituminous coal	1	4
	Clay		5
Lower Bench	Bituminous coal		3½
	Sulphur band		½
	Bituminous coal		11½
	Sulphur lense		½
	Bituminous coal		6½
	Clay		

Sample No. 51 of the bituminous coal from the lower bench yielded at the rate of 21.8 gallons of low-temperature tar per ton, while sample No. 52 representing the upper bench gave 23.5 gallons.

A cannel coal, occurring at the Upper Kittanning horizon, was at one time extensively mined north of Deegan in eastern Marion and western Venango townships by the Butts Cannel Coal Company. It lies about 130 feet above the Vanport limestone horizon. At the time of the writer's visit, in the fall of 1918, the mine had already been abandoned. The cannel coal is said to have been mined from underneath an area of approximately 250 acres. In thickness it ranged from 16 to 30 inches, with from three to four feet of cannel shale overlying it in places. At the old mine mouth 14 inches of cannel shale show above the cannel coal, only the upper portion of which is exposed. Sample No. 53 of the cannel coal was obtained from an old slack dump of the Butts Cannel Coal Company. It yielded at the rate of 37.2 gallons of oil per ton. Sample No. 54 of the cannel shale was obtained by breaking off small pieces at random from large lumps on a waste dump at the mouth of the mine. It showed a yield of 28.9 gallons.

The above described area of cannel coal underlies the top of the hill on the west side of the north branch of Seaton Creek at Deegan. Cannel coal also occurs near the tops of the hills immediately to the south, east, and northeast of Deegan, but outcrops are nowhere exposed. It has been encountered in old prospect drifts and shafts. The area thus underlain, however, appears to be very limited and, according to the best evidence obtainable, the cannel coal nowhere exceeds 30 inches in thickness.

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[1] Butts, Charles. Am. Jour. Sci., Vol. XLVI, 4th series, p. 524, 1918.

Another small cannel coal deposit very similar to the above, also at the Upper Kittanning horizon, occurs in southern Washington Township, about 1½ miles southwest of North Washington. In a small country bank, operated by the Myron Campbell heirs, the following section was measured about 200 feet from the mouth of the drift.

Section of Upper Kittanning bed near North Washington.

	Ft.	In
Gray shale		
Carbonaceous shale		4
Cannel coal	3	0
Carbonaceous shale		4
Clay		

Sample No. 55 of the cannel coal gave a yield at the rate of 34.4 gallons of oil per ton, and sample No. 56 of the carbonaceous shale overlying it gave 11.8 gallons.

In Parker Township, along a small creek near the Shakeley School, 1½ miles southeast of Bruin, the Upper Kittanning horizon shows 13 inches of cannel shale (top not exposed) overlying 2 inches of bituminous coal. The floor is sandy shale. Sample No. 57 of the cannel shale from the outcrop showed a yield of 27.3 gallons of oil per ton.

At a number of places in Worth, Brady, Clay, Franklin, and Center townships, in central Butler County, cannel coal and shale appear at a horizon probably corresponding to the Upper Kittanning coal, although Mills,[1] in connection with the geological survey of the Butler quadrangle, has correlated it with the Lower Freeport. The outcrops of the cannel coal and shale horizon and the localities from which samples were obtained are shown in figure 11. Although cannel coal and shale are scattered over a considerable area, the deposit is by no means continuous over all of it and those portions over which it is of workable thickness are probably very limited. This can only be deter-

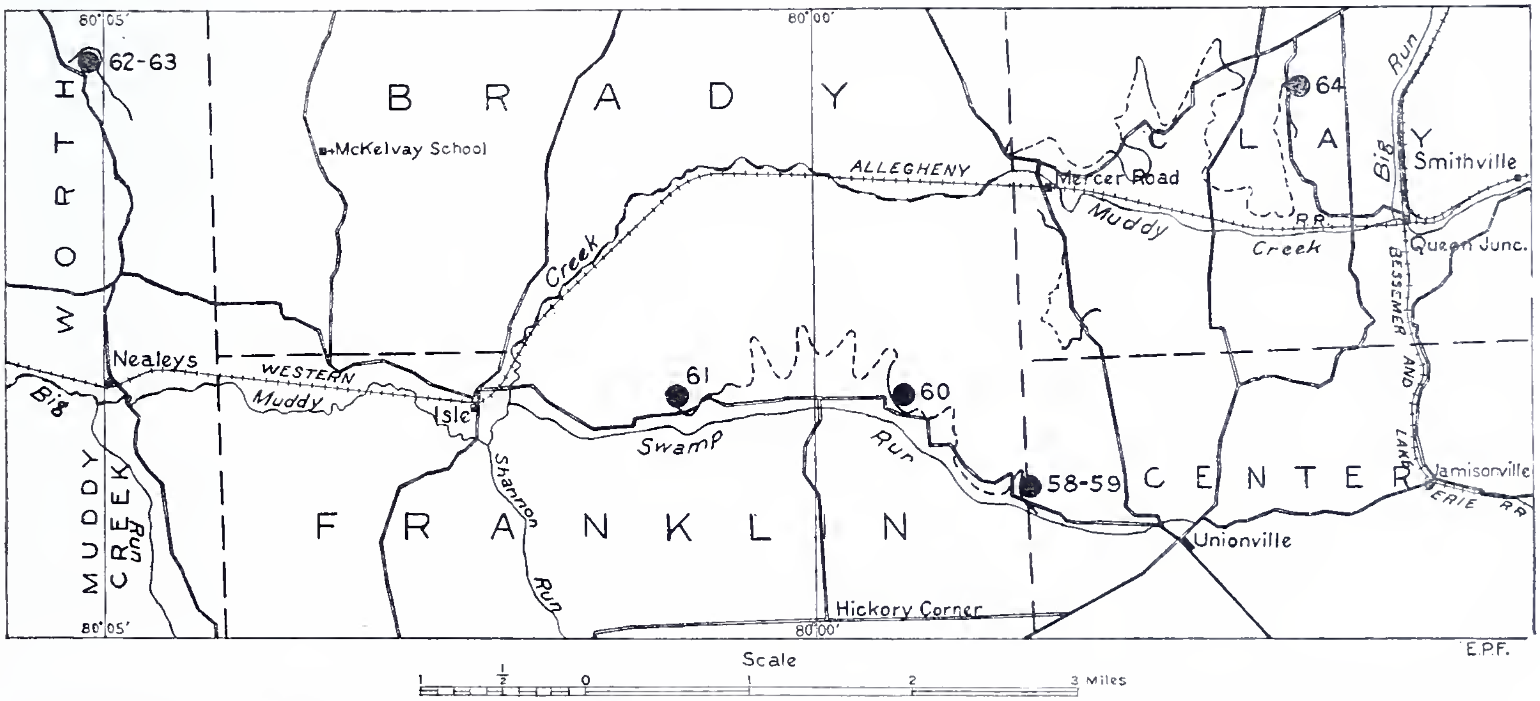

FIGURE 11. Map showing outcrop of cannel coal and shale at what is probably Upper Kittanning horizon, central Butler County, Pa.

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[1] U. S. Geol. Survey, Bull. 641, p. 315, 1917.

mined by further prospecting, preferably with a core drill.

A drill record, furnished by S. J. Taylor, of Slippery Rock, of a hole put down near the forks of the road northwest of the Mount Union (or Zion) church, in Worth Township, shows the position of the cannel coal to be as follows. with respect to the Middle Kittanning coal which is the bed that is extensively mined in this district:—

Section near Mount Union Church, Worth Township.

	Ft.	In.	
Soil	11	0	
Sandstone	14	0	
Shale	7	0	
Coal	3	6	
Fire clay	1	6	
Shale	14	0	
Coal	1	0	
Fire clay	9	0	
Shale	13	0	
Sandstone	78	0	
Shale	18	6	
Cannel coal	2	0	Probably Upper Kittanning
Bituminous coal	3	7	
Fire clay	0	4	
Coal	1	0	
Fire clay	5	7	
Sandstone	75	0	
Shale	13	0	
Coal	3	2	Middle Kitanning
Fire clay			

About 1600 feet north of this locality in the country bank of G. W. Currie, only one foot of cannel coal appears overlying 1½ feet of bituminous coal; while in two other drill holes, one 1200 feet southeast of the first and the other 5400 feet northwest, no cannel coal whatever was encountered.

As measurable outcrops of the cannel coal and shale are rare and the prospect drifts are in practically every case inaccessible, it is very difficult to get any reliable data on the quantity of cannel coal and shale present. In the extreme southwest corner of Clay Township, along the Mercer road, the following section is exposed:—

Section of coal bed in Clay Township.

	Ft.	In.
Dark, nearly black carbonaceous shale		
Cannel shale	1	9
Gray shale	2	4
Bituminous coal	1	3
Bottom not exposed.		

A number of years ago, a prospect opening was made in a cannel coal at this horizon on the Jennings C. McCandless farm along Swamp Run in Franklin Township, one mile west of Unionville. The drift had caved and hence was inaccessible at the time of the writer's visit in 1920. McCandless stated that the cannel shale and coal showed the following thicknesses:—

Section of coal bed near Unionville.

	Ft.	In.
Lean cannel shale	3	0
Rich cannel shale	2	6
Cannel coal	2	6
Clay	1	6
Bituminous coal		8

Sample No. 58 of the cannel coal obtained from the dump at the mouth of the drift, showed a yield at the rate of 41.4 gallons of oil per ton. Sample No. 59 of the cannel shale, also taken from the dump. gave 33.2 gallons.

A mile northwest of the above locality, along Swamp Run, at the mouth of another old and inaccessible prospect drift on the J. M. McBride farm. 13 feet 8 inches of badly weathered cannel shale are exposed. Sample No. 60 of the cannel shale was taken from the dump. It showed a yield of 20 gallons of oil per ton.

Sample No. 61 of cannel shale was obtained from a dump at a similar prospect drift still farther down Swamp Run about 1½ miles east of Isle. From it oil was obtained at the rate of 20.7 gallons per ton.

In eastern Worth Township. two miles north of Nealey's the cannel coal has been opened in a country bank on the form of G. W. Currie. The following section was measured in the main drift about 325 feet from the mouth:—

	Ft.	In.
Top not exposed		
Carbonaceous shale	2	4
Cannel coal	1	0
Bituminous coal	1	7
Clay		

Sample No. 62 of the cannel coal gave a yield at the rate of 33 gallons of oil per ton. Sample No. 63 of the carbonaceous shale produced at the rate of 14.8 gallons per ton.

Sample No. 64 was obtained from the dump of an inaccessible prospect drift in Clay Township, one mile northwest of Queen Junction. It gave a yield of 36.3 gallons of oil per ton.

In southwestern Forward Township, along Breakneck Creek, a thin layer of cannel shale overlies the Upper Freeport coal in some places. In a country bank with a sandstone roof and clay floor, on the farm of John Marburger, two miles southeast of Evans City, 4 inches of cannel shale lies on 17 inches of bituminous coal and is overlain by 2 inches of carbonaceous shale. Sample No. 65 of the cannel shale gave a yield at the rate of 32.6 gallons of oil per ton.

Center County.

Rocks of Pennsylvanian age occur only in the extreme western part of Center County, in that portion west of the Allegheny Front. In this area, the Pottsville, Allegheny, and Conemaugh formations are represented. The coal beds are confined to the Allegheny formation.

The coals have fixed-carbon percentages ranging from 75 to 77 when computed on a pure coal basis. They are of semi-bituminous rank, belonging to the Sewellite type of Ashley. Cannel coals and carbonaceous shales associated with them would not be expected to yield a large quantity of oil per ton on account of the excessive metamorphism that the strata have undergone, which has driven off much of the volatile matter originally present in these materials. This is borne out by tests that have been made on samples secured from the area.

About one mile southwest of Philipsburg, a canneloid semi-bituminous coal was being mined by the Moshannon Coal Company during 1918 in their No. 11 mine. It occurs in what is locally known as the "B" bed, which corresponds to the horizon of the Lower Kittanning coal. Sample No. 67, representing the canneloid semi-bituminous coal, was obtained along an entry off the main south heading about 2000 feet from its mouth. It gave a yield at the rate of only 9 gallons of oil per ton. The following section was measured at this point:—

Section of Lower Kittanning bed near Philipsburg.

	Ft.	In.
Shale roof		
Semi-bituminous coal	1	0
Bony coal		6
Semi-bituminous coal		8
Canneloid semi-bituminous coal	3	5½
Bony coal		8
Clay floor		

Sample No. 66 of the semi-bituminous coal was obtained along the same heading about 1100 feet farther south, where the following section was measured:—

	Ft.	In.
Shale roof		
Semi-bituminous coal		10
Carbonaceous shale with streaks of coal		7
Semi-bituminous coal	2	11
Clay floor		

The semi-bituminous coal gave a yield of 10 gallons of low-temperature tar per ton.

In a distance of 1,100 feet, the canneloid semi-bituminous coal gradually thins until at the point where sample No. 66 was taken, only 7 inches of carbonaceous shale remain, and the canneloid has been supplanted by ordinary coal. The canneloid coal extends northward toward Philipsburg, but it is not known just how far. It was not encountered in the shaft of the West Penn Power Company at the northeast end of the town.

The Moshannon No. 11 mine was visited by Ashley[1] in 1914. At that time it was being operated by the Lula Coal Mining Company. He estimated that an area of at least 100 acres was underlain by about four feet of the canneloid coal.

Clearfield County.

Strata of Pennsylvanian age underlie most of Clearfield County. Only in a few places, where streams cut across the axes of the major anticlines, are the Mississippian formations, exposed by erosion. Of the Pennsylvanian strata, the Pottsville, Allegheny, and Conemaugh series are represented.

The coals range in fixed-carbon percentages, computed on a pure coal basis, from 65 in the northwestern part of the county to 78 in the southeastern. They are of bituminous and semi-bituminous rank, and belong to the Connellsite, Sewellite, and Pocahontite types of Ashley, with the Sewellite type predominating. Cannel coals and shales, yielding large amounts of oil per ton, therefore, probably do not occur within the county. Tests on samples obtained are in accordance with this conclusion.

A canneloid semi-bituminous coal has been mined north of Woodland by the Woodland Cannel Coal Company. The Cannel Crest mine of this company is near the head of Buck Run, a short tributary of the west branch of Susquehanna River. In 1918 this mine had a daily output of 350 to 400 tons. A. B. Lansberry was also mining coal from this bed on adjoining property on the west side. His mine is at the head of Abes Run, another short tributary of the Susquehanna. In 1918 the daily output was 200 to 250 tons.

The writer's visit to the locality was too brief to identify the horizon of this coal. Mr. A. E. Woolridge, of the Woodland Cannel Coal Company, who has given considerable attention to this question, has come to the conclusion that it is the "B" seam or Lower Kittanning.

The deposit is lenticular with the long axis trending approximately N. 15° W. Originally, the basin was 1½ to 2 miles long and ¾ to 1 mile wide. About one-half of the deposit has been removed by erosion.

Sample No. 68 of the canneloid semi-bituminous coal was taken in room 23 off of the fourth left entry of the Cannel Crest mine. The bed is 4 feet 10½ inches thick at this place. Near the mouth of the main entry it showed the following development:—

Section of coal bed near Woodland.

	Ft.	In.
Shale roof		
Draw slate		8-10
Canneloid shale		2
Canneliod semi-bituminous coal ..	3	9
Canneloid shale		10
Clay		7½
Bituminous coal		5
Clay		4½
Sandstone		

The canneloid semi-bituminous coal gave a yield at the rate of 10.3 gallons of oil per ton.

Another bed of cannel coal, known as the "Red Ash", to distinguish it from the "White Ash", which has just been described was at one time mined just north of Woodland. It lies stratigraphically 40 to 50 feet above the latter, and therefore, corresponds approximately to the Middle Kittanning horizon, if the latter is Lower Kittanning. This deposit of only about 45 acres has been mined out. Sample No. 69 consists of weathered slack from this bed, obtained from an old dump on the Overly farm. It yielded at the rate of 11.1 gallons of oil per ton.

Several small deposits of cannel coal occur southeast of Houtzdale, near the junction of Whiteside Run and Moshannon Creek. During 1918, one of these was being worked at the Sterling No. 2 mine on the north side of Moshannon Creek, just below the mouth of Whiteside Run.

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[1] Ashley, George H. Cannel coal in the United States, U. S. Geol. Survey Bull. 659, p. 56, 1918.

This bed is about 80 feet above what is called the "B" seam or Lower Kittanning coal in this district, and therefore, probably belongs to the Upper Kittanning horizon. Another bed has been partially uncovered 32 feet below it which also contains some cannel coal. It has not been opened sufficiently to be measured. One-half mile down Moshannon Creek on the same side, the "B" seam or Lower Kittanning coal is being worked at the Sterling No. 1 mine. 56 feet above the latter at this place, there is an old opening, now caved, on a bed which also contained some cannel coal. This apparently is also below the bed worked at the Sterling No. 2 mine, and therefore, corresponds to the middle bed, which probably represents the Middle Kittanning horizon. A number of other openings along the side of the hill at this horizon disclose only bituminous coal.

The following section was measured along the main entry of the Sterling No. 2 mine:—

Section of Upper Kittanning (?) bed near Houtzdale.

	Ft.	In.
Carbonaceous shale, thickness not determined.		
Canneloid shale		4½
Canneloid semi-bituminous coal	4	1
Semi-bituminous coal	1	6
Shale		

Sample No. 70 of the semi-bituminous coal yielded low-temperature tar at the rate of 10.4 gallons per ton. Sample No. 71 of the canneloid semi-bituminous coal gave 9.3 gallons of oil per ton Sample No. 72 of the canneloid shale gave 4.5 gallons, and sample No. 73 of the lower portion of the carbonaceous shale gave 1.5 gallons.

Cannel coal was at one time also obtained at the Katherine mine of A. Stolz on the west side of Moshannon Creek just above the mouth of Whiteside Run, and one-half mile farther southwest on the same side of the creek at the Keystone mine of Hurly, Wilson, and Law. Both of these mines are now abandoned. They were not visited by the writer, but description of the deposits may be found in U. S. Geological Survey bulletin 659, page 57.

Sample No. 74 of semi-bituminous coal was obtained from the Lower Freeport bed, also locally known as the "D" or Moshannon bed. It yielded at the rate of 6.8 gallons of low-temperature tar. The sample was obtained at the Hartley No. 1 mine north of Graham Station. The following section was measured in the mine at the point where the sample was taken:—

	Ft.	In.
Shale roof		
Semi-bituminous coal	3	3½
Shale		1½
Semi-bituminous coal	1	2¾
Clay floor.		

Fayette County.

In Fayette County horizons from the Catskill sandstone of the Devonian to the Greene formation of the Permian are exposed at the surface. In the extreme eastern portion of the county, coals containing fixed-carbon percentages as high as 72, computed on a pure coal basis, are present: while in the western part of the county, some run as low as 59. The coals belong to the Pittsite, Connellsite, and Sewellite types of Ashley, with the Connellsite type predominating. Carbonaceous shales, sufficiently rich in volatile matter to be considered as possible sources of oil, therefore, are more apt to be found in the western than in the eastern part of the county.

Only one sample, a cannel shale from the Redstone horizon, from the vicinity of New Geneva was tested during the present investigation. This occurrence will be referred to again under the description of that bed in Greene County.

Greene County.

The strata exposed at the surface in Greene County belong to the Pennsylvanian and Permian series. Formations from the Conemaugh to the Greene, inclusive, are represented. The highest beds of the latter found in Pennsylvania occur in this county. The nearly horizontal structure is modified slightly by a number of anticlines and synclines which cross the county in the general northeast-southwest direction. Only the upper-most portion of the Conemaugh appears at the surface. It and the Monongahela formation crop only along Monongahela River and its major tributaries in the eastern part of the county and over a small area along the Dunkard and Enslow Forks of Wheeling Creek in the extreme northwestern corner. Over most of the county, the Washington and Greene formations alone appear at the surface.

The coals of the county have fixed-carbon percentages ranging from 56 to 63, computed on a pure coal basis. They are of bituminous rank, belonging to the Belmontite and Pittsite types of Ashley, with the latter predominating. Cannel coal and shale deposits discovered within the confines of the county deserve attention as possible sources of oil.

In the vicinity of Greensboro, in southeastern Greene, and New Geneva, in southwestern Fayette County, a cannel shale occurs associated with a thin bed of bituminous coal at what is probably the Redstone horizon. The bed is well exposed along the road from Greensboro to Mapletown at a point about one-half mile northwest of the town at an elevation of 960 feet. At this point the following section was measured:—

Section of Redstone bed near Greensboro.

	Ft.	In.
Gray shale		
Fissile carbonaceous shale	3	6
Bituminous coal	1	6
Cannel shale	4	6
Gray shale		

The top of the Redstone coal at this place lies 40 feet above the top of the Pittsburgh bed.

Sample No. 76 of the cannel shale was obtained from a small opening about 40 feet long, one-third of a mile northeast of the above locality on the E. R. Gabler farm. The following section is exposed:—

	Ft.	In.
Fissile carbonaceous shale	5	
Cannel shale	6	3
Cannel shale	Bottom not exposed	

The cannel shale gave a yield at the rate of 26.6 gallons of oil per ton.

Along the west side of Monongahela River 1½ miles north of the above opening at the Alicia Mine No. 2, the cannel shale is not developed in the Redstone bed. The following section is exposed at this place:—

Section near Greensboro.

		Ft.	In.
	Sandstone		
	Fissile shale		10
	Sewickley coal	5	4
	Fissile sandy shale	8	5
	Limestone	5	2
	Shale with calcareous concretions	1	
	Light gray shale	3	
	Carbonaceous shale		4
	Coal		5
	Limestone	6	4
	Fissile gray shale	26	10
	Fissile dark gray shale	1	6
	Carbonaceous shale	2	2
Redstone	Coal		1
	Carbonaceous shale		½
	Coal		11
	Carbonaceous shale		¼
	Coal		8
	Carbonaceous shale		¼
	Coal	1	1
	Shale		2
	Limestone	13	
	Shale	29	10
	Carbonaceous shale	3	
	Pittsburgh coal	9	

The Redstone horizon was also observed at two places on the east side of the Monongahela Valley in Fayette County, opposite Greensboro. One outcrop occurs in a field northeast of New Geneva at an elevation of about 1,100 feet. 5 feet 6 inches of cannel shale were exposed in a prospect cut from which about three feet of soil had been removed. Neither the top nor the botttom of the shale is exposed. Sample No. 75 was obtained here. It gave only 10.6 gallons of oil per ton. The material was much weathered, which probably accounts for the low yield of oil. Two-fifths of a mile south of this opening, at about the same level, the following section can be seen along the roadeast of New Geneva:—

Section of Redstone near New Geneva.

	In.
Gray shale	
Coal	9½
Shale	½
Coal	6
Shale	½
Coal	4
Bony coal	8
Coal	16
Bottom of coal not exposed.	

The writer was informed that Alexander Evans and Ellis Stevenson in 1859 considered mining the Redstone cannel shale on the Gabler farm, at that time the Stevenson farm, at Greensboro for oil distillation. On account of the development of the petroleum industry shortly afterwards, however, the project was abandoned.

From the data at hand, it appears that the development of the cannel shale at the Redstone horizon at Greensboro and New Geneva is a purely local one. The shale does not extend very far either north or south of Greensboro. It is hard to say just how far west it extends as this horizon does not crop out again in that direction.

Sample No. 77 was obtained at the mine of S. I. Black, west of Greensboro, from the Sewickley, or what is locally known as the Mapletown bed. The sample was taken about 90 feet from the mouth of the main entry, where the following section was measured:—

Section of Sewickley bed near Greensboro.

	Ft.	In.
Gray shale		
Coal	2	5½
Shale		¼
Coal	2	
Gray shale.		

A yield at the rate of 23.8 gallons of low-temperature tar per ton was obtained from this sample.

Sample No. 78 of a carbonaceous shale was obtained from the Uniontown horizon from a weathered outcrop along a small run emptying into Monongahela River one-fourth of a mile below Whiteley Creek, in Monongahela Township. The following section was exposed:—

Section of Uniontown bed near mouth of Whiteley Creek.

	Ft.	In.
Gray shale		
Carbonaceous shale	1	
Carbonaceous sandy shale		11
Gray shale	2	
Coal		5½
Gray shale.		

A yield at the rate of 7.4 gallons of oil per ton was obtained from the sample.

Sample No. 79 of bituminous coal from the Waynesburg horizon, was obtained in the Moredock mine of the American Steel Company, 1½ east of Waynesburg. The Waynesburg bed shows the following development in this locality:—

Section of Waynesburg bed near Waynesburg.

	Ft.	In.
Sandstone		
Shale		2-10
Coal	1	4½
Clay	1	8½
Bony coal		6
Coal	1	11½
Clay.		

A yield at the rate of 26.2 gallons of low-temperature tar per ton was obtained from this coal.

Samples Nos. 80 and 81 represent carbonaceous shales occurring below and above the Washington coal along Purmans Run at Waynesburg. The outcrop from which they were obtained, is only poorly exposed. Stevenson[1] measured the following section at this locality:—

Section at Waynesburg.

	Ft.	In.
Shale with clay ironstone nodules	7	6
Limestone	3	0
Sandstone	18	0
Carbonaceous shale	3	0

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[1] Stevenson, J. J. Report of progress in the Greene and Washington district of the bituminous coal fields of western Pennsylvania. Pennsylvania Second Geol. Survey. Report K, p. 149. 1876.

		Ft.	In.
	Limestone	3	6
	Shale	6	0
Washington bed	Coal		8
	Clay		5
	Coal	1	3
	Clay and shale	2	6
	Sandy shale	12	0
	Carbonaceous shale	8	0

Sample No. 80 came from the lower bed of carbonaceous shale and No. 81 from the upper. The samples represent only a thickness of about seven inches of the least weathered material in each bed. The former yielded at the rate of 11.1 gallons of oil per ton and the latter at the rate of 2.9 gallons.

In Washington Township, in a prospect opening on the east side of Boyd Run, two miles above its mouth, the following section was obtained at the Upper Washington coal horizon:—

Section of Upper Washington bed on Boyd Run.

	Ft.	In.
Shale		
Bony coal	1	6
Coal	2	1
Cannel shale (bottom not exposed)		11
Covered	4	7
Upper Washington Limestone		

Sample No. 82 of the cannel shale produced at the rate of 11.2 gallons of oil per ton.

Indiana County.

The strata appearing at the surface in Indiana County belong to the Mississippian and Pennsylvanian series. Of the latter, the formations from the Pottsville to the Monongahela, inclusive, are represented, the last mentioned being confined to comparatively small areas in the southwestern part of the county.

The coals have fixed-carbon percentages, computed on a pure coal basis, ranging from 63 in the western to 79 in the eastern part of the county. They are of bituminous and semi-bituminous rank, belonging to the Pittsite, Connellsite, Sewellite, and Pocahontite types of Ashley, with the Connellsite type predominating. Cannel coals and carbonaceous shales with sufficient volatile matter to be of value as possible future sources of oil, therefore, can be expected to occur only in the northwestern part of the county.

A deposit of cannel coal belonging to the Upper Kittanning horizon occurs at the head of Crooked Run, about three miles south of Savan Station on the Indiana branch of the Buffalo, Rochester, and Pittsburgh Railroad. Cannel coal was being mined from this deposit in 1918 by the Bicknell Brothers. The deposit is channel-like in form. At the mine the channel has a trend of N. 30½° W. and a width of about 400 feet. This coal also crops southeast of this locality on the opposite side of the ridge on the old George Barr farm near Deckers Point where it was formerly mined on a small scale.

The entry from which coal was being taken in 1918 was along the northeast side of the channel. The floor at this point dips rather abruptly towards the middle of the channel. On the opposite side, the dip is said to be somewhat gentler. The following section was measured a short distance in from the mouth of the entry:—

Section of Upper Kittanning bed 3 miles south of Savan Station.

	Ft.	In.
Dark gray shale		
Cannel shale		10
Cannel coal	2	8
Bituminous coal		11
Shale		

Along the middle of the channel, as much as 15 feet of cannel coal is said to have been encountered in places. The deposit has been previously described by both Platt and Ashley.[1]

Sample No. 83, representing the cannel coal, gave a yield at the rate of 19.0 gallons of oil per ton; and sample No. 84 of the cannel shale, gave 5.3 gallons per ton. The cannel coal has a columnar structure. Much of it is also of the "curly" variety. It has lost much of its volatile matter through metamorphism, which accounts for its relatively low yield of oil.

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[1] Platt, W. G. Report of progress in Indiana County. Pennsylvania Second Geol. Survey Report H-4, pp. 228-231, 1878.
Ashley, George H. Cannel coal in the United States. U. S. Geol. Survey Bull. 659, p. 58, 1918.

Sample No. 85 came from a layer of bone in the Upper Freeport coal, as developed in the No. 2 mine of the Jefferson and Clearfield Coal and Iron Company at Ernest. It produced at the rate of 10.5 gallons of low-temperature tar per ton. The following section was measured in room 13 on the right side of the third butt heading off from the third entry to the southwest, where the sample was taken:—

Section of Upper Freeport coal at Ernest.

	Ft.	In.
Sandstone		
Coal	1	2½
Sulphur band		⅜
Coal		4¼
Sulphur band		⅛
Bone (with streaks of coal)		8½
Coal	3	7½
Shale		1
Coal		5
Clay		

Near the head of a small run which enters Cowanshannock Creek from the south at the Indiana-Armstrong County line in South Mahoning Township, east of Barnards Post Office, a carbonaceous shale in the lower portion of the Conemaugh formation at approximately the Bakerstown horizon is very poorly exposed. At the outcrop it appears as a very fissile carbonaceous shale having a cannellike appearance. Thin laminae of coal may be seen in it. At the locality examined 16 feet are exposed, resting upon sandstone. A prospect drift was at one time run in on it but this has collapsed. Sample No. 86 was obtained by breaking off small pieces from some of the larger blocks lying on the dump. The material, which was in a much weathered condition, gave a yield at the rate of only 6.3 gallons of oil per ton.

Platt[1] obtained the following section at this locality:—

Section near Barnards.

	Ft.	In.
Limestone—hilltop		
Concealed	75	
Carbonaceous shale	10	
Sandstone	4	
Clay	2	
Coal	thin bed	
Shale	10	
Red shale	8	
Sandstone and shale	70	
Gray shale	30	
Concealed	50	
Coal (Gallitzin)	1	6
Sandstone	50	
Coal (Upper Freeport).		

Jefferson County.

The outcropping consolidated rocks of Jefferson County are of Mississippian and Pennsylvanian age. The latter period is represented by the Pottsville, Allegheny, and Conemaugh formations. The coals have fixed-carbon percentages, computed on a pure coal basis, ranging from 58 to 67. They are of bituminous rank, and belong chiefly to the Pittsite type of Ashley, although in the southeastern portion of the county some Connellsite coals are also present.

Only one sample from the county, namely No. 87, representing a cannel shale from the roof of the Lower Freeport coal, was tested during the present investigation. It was obtained in room 2 along the fifth left entry off the main entry in the No. 8 or Big Ben Mine of the Jefferson Coal Company, at Coal Glen. The following section was measured at this point:—

Section of Lower Freeport bed at Coal Glen.

	Ft.	In.
Light gray sandy shale		
Cannel shale		4
Bituminous coal	3	9
Shale		

The cannel shale produced at the rate of 29.6 gallons of oil per ton.

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[1] Platt, W. G. Report of progress in Armstrong County, Pennsylvania Second Geol. Survey, Report H5, p. 90, 1880.

Lawrence County.

Strata belonging to the Pottsville, Allegheny, and lower Conemaugh formations appear at the surface in Lawrence County. A cannel shale, probably belonging to the Upper Kittanning horizon, crops on the Thomas M. Stewart farm, 1¼ miles southeast of Mountair, in Little Beaver Township. It was at one time opened by a prospect drift which is now caved. Sample No. 88 of the cannel shale was obtained from the dump at the site of the old opening. It yielded at the rate of 37.4 gallons of oil per ton.

J. R. Stewart informed the writer that the following section was exposed in the drift:—

Section of Upper Kittanning (?) bed near Mountair.

	Ft.	In.
Sandstone		
Cannel shale	8 to 9	
Bituminous coal	2	10
Dark shale.		

Luzerne County.

Sample No. 89 represents true anthracite, and No. 90, a canneloid anthracite from the Hillman bed. taken in the Stanton No. 7 mine of the Lehigh and Wilkes-Barre Coal Company, at Wilkes-Barre . The bed showed the following section in room 8 off of the number 6 slope, where the samples were taken: –

Section of Hillman bed at Wilkes-Barre.

	Ft.	In.
Clay		
Shale with streaks of coal	2	0
Bony anthracite	1	4
Bone		1½
Anthracite		4
Bone		1½
Anthracite		5
Bone		1
Anthracite		10
Bone		1
Anthracite		5½
Bone		1
Anthracite		7½
Canneloid anthracite		4½
Anthracite	1	9
Clay.		

Carbonization tests on these samples indicate that devolitilization of the coal through metamorphism has reached a point where the coal will no longer yield any oil or tar. Only fixed gases are given off.

Lycoming County.

A number of small outliers of Pennsylvanian strata, containing coal, occur in the northern portion of Lycoming County. Sample No. 91 was obtained from the lower bench of the "B" bed in the mine of the Ralston Coal Company, at Ralston. It is a semi-bituminous coal which produced at the rate of only 1.9 gallons of low-temperature tar per ton. The bed has the following development at the mine:—

Section of B bed at Ralston.

	Ft.	In.
Sandstone		
Semi-bituminous coal	2	1
Shale	3	3
Semi-bituminous coal	2	2
Clay		

The strata of Lycoming county have undergone too much metamorphism to have associated with them coals or carbonaceous shales that contain sufficient quantities of volatile matter to be of value as possible future sources of oil.

Mercer County.

The outcropping stratified rocks of Mercer County are of Mississippian and Pennsylvanian age. Of the latter, only the Pottsville and Allegheny formations remain. The strata lie almost horizontal with only a very slight dip towards the south. No well defined anticlines or synclines traverse the county although numerous local rolls are present.

The coals have fixed-carbon percentages, computed on a pure coal basis, ranging from 56 to 61. They are of bituminous rank, belonging to the Belmontite and Pittsite types, with the former probably predominating.

On the southeast side of Neshannock Creek, in Springfield Township, ½ mile northeast of Leesburg Station, a cannel shale occurs at what

White[1] has identified as the Sharon coal horizon. It has been opened by a prospect drift, which, however, was inaccessible at the time of the writer's visit in 1920. E. S. Rudolph, of Leesburg Station, furnished the following section:—

Section of Sharon coal at Leesburg Station.

	Ft.	In.
Sandstone		
Bituminous coal	1	0
Cannel shale		8-10
Bituminous coal	1	6-8
Clay		

Sample No. 92 of the cannel shale was obtained from large lumps thrown out on the dump. It gave a yield at the rate of 48.3 gallons of oil per ton.

Sample No. 93 of bituminous coal from the Brookville bed was obtained in the Diamond No. 3 mine of the Scotch Hills Coal Company, two miles east of Grove City. In the 17th room on the left side of the 13th right entry of the mine at the place where the sample was taken, the following section was measured:—

Section of Brookville bed near Grove City.

	Ft.	In.
Sandstone		
Shale	0-4	
Coal	1	4½
Bone		1
Coal	1	1½
Sulphur band		1
Coal		2
Sulphur lense		½
Coal	1	5
Clay		

The bituminous coal produced at the rate of 24.6 gallons of low-temperature tar per ton.

Sullivan County.

There are a number of small outliers of Pennsylvanian rocks containing coal in the central portion of Sullivan County, the most important of which is the one around Bernice and Lopez. The coals have fixed-carbon percentages, computed on a pure coal basis, ranging from 89 to 90. They are of semi-anthracite rank, belonging to the Bernicite type of Ashley. No carbonaceous shales rich in volatile matter could be expected to occur associated with them.

Sample No. 94 of semi-anthracite was obtained from what is locally known as the Bernice or "B" bed in the Murray mine of the Northern Anthracite Coal Company, at Lopez. The following section was measured in the Miller heading on the tenth pillar from the main entry:—

Section of Bernice bed at Lopez.

	Ft.	In.
Sandstone		
Shale	1	4
Semi-anthracite	2	4
Shale		3
Semi-anthracite	3	8½
Sandstone or shale		(varies)

On low-temperature carbonization, the coal gave only a trace of tar. Light oil at the rate of one-tenth gallon per ton was recovered by charcoal adsorption from the gases evolved.

Tioga County.

A number of small disconnected areas of coal-bearing Pennsylvanian rocks remain as erosion remnants in a belt which extends in a northeasterly direction across the southeastern portion of Tioga County. There are also a number of other small outliers in the central western portion of the county. The coals have fixed-carbon percentages, computed on a pure coal basis, ranging from 72 to 80. They are chiefly of semi-bituminous rank, belonging to the Sewellite and Pocahontite types.

The most important area is between Blossburg and Fall Brook. The following generalized section of the coal-bearing strata of this locality was furnished the writer by Theo. A. Schmidt, mining engineer with the Morris Run Coal Mining Company:—

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[1] White, I. C. The geology of Mercer County, Pennsylvania Second Geol. Survey Report Q3, p. 88, 1880.

Section near Blossburg.

		Ft.	In.
	Soil		
	Sandstone		
Rock bed	Coal	3	0
	Clay	5	0
	Sandstone	34	0
	Carbonaceous shale	4	0
Seymour bed	Bone		10
	Coal	2	6
	Sandstone	50-70	
Morgan bed	Bone		9
	Coal	2	9
	Clay	1	4
	Coal	1	0
	Clay	5	0
	Shale	1	6
Cannel bed	Coal	1	6
	Cannel shale	2	6
	Coal	1	2
	Sandstone	20	
One-foot bed	Coal	1	0
	Sandy shale	7	0
	Shale	11	0
Bloss bed	Bone		9
	Coal	2	4
	Clay	4	0
	Coal	1	2
	Clay	3	0
	Sandstone	7	0
Bear Creek bed	Coal	2	4
	Shale	4	0
	Sandstone		

Sample No. 95 represents the coal from the Bloss bed, obtained at the mine of the Bower Coal Company, at Blossburg. The sample was taken in the first left entry, 275 yards from the mouth of the mine where the bed has the following section:—

Section of Bloss bed at Blossburg.

	Ft.	In.
Sandy shale		
Coal		3½
Carbonaceous shale		¾
Coal		1½
Bone		1½
Coal	2	3
Dark gray sandy shale.		

The semi-bituminous coal from this mine gave a yield at the rate of 6.2 gallons of low-temperature tar per ton.

Samples No. 96 and 97 are from the Cannel bed, taken in the No. 15 drift of the Morris Run Coal Company, at Morris Run. The bed shows the following development along this drift:—

Section of Cannel bed at Morris Run.

	Ft.	In.
Sandstone		
Carbonaceous shale		11
Semi-bituminous coal	1	8
Canneloid shale	1	10
Clay		5
Semi-bituminous coal		11½
Shale		½
Semi-bituminous coal		3
Clay		

Sample No. 96 represents the entire bench of canneloid shale. It yielded at the rate of 2.5 gallons of oil per ton. No. 97 represents only the lower 7 in. of canneloid shale. It produced at the rate of 2.6 gallons of oil per ton.

Washington County.

In Washington County strata of Pennsylvanian and Permian age appear at the surface. Formations from the Conemaugh to the Greene, inclusive, are represented. The coals have fixed-carbon percentages, computed on a pure coal basis, ranging from 55 to 65. They are of bituminous rank, belonging to the Belmontite and Pittsite types. The deposits have not undergone excessive metamorphism and from that standpoint, therefore, conditions are favorable for the occurrence of cannel coals and shales sufficiently high in volatile matter to be considered as possible future sources of oil. Hence wherever such deposits are found in the county their yield of oil should be investigated. Thus far none have been reported.

Sample No. 98 represents a bituminous coal from the Pittsburgh bed obtained in the Arden No. 2 mine of the Meadowland Coal Company.

1¼miles northwest of Arden, in Chartiers Township. The sample was taken in room 18 off of the 6th right entry from the 18th face entry where the coal showed the following development:

Section of Pittsburgh bed near Arden.

	Ft.	In.
Sandy shale		
Coal		2
Shale		4
Coal	2	10½
Black shale		½
Coal		1¾
Black shale		½
Coal	2	7¾
Shale		

The bituminous coal yielded at the rate of 29.5 gallons of low-temperature tar.

Sample No. 99 was taken from the main bench of the Pittsburgh bed at the No. 2 mine of the Ellsworth Collieries Company, at Ellsworth. The following composite section of the bed was measured in the mine:—

Section of Pittsburgh bed at Ellsworth.

		Ft.	In.
	Sandstone		
Roof coal (not mined)	Coal		4½
	Shale		3
	Coal		6½
	Carbonaceous shale		¼
	Coal		4½
	Carbonaceous shale		¼
	Clay	1	0
Main bench (mined)	Coal	3	6
	Shale		¼
	Coal		1¾
	Shale		½
	Coal	2	8
	Clay		

Low-temperature tar at the rate of 23.3 gallons per ton was obtained from the bituminous coal by carbonization in an 1800 c. c. capacity retort.

Sample No. 100 represents coal washer refuse, obtained by washing Pittsburgh coal at the Ellsworth Collieries Company's washer at Ellsworth. It yielded only at the rate of 3.5 gallons of low-temperature tar per ton.

Sample No. 101 of bituminous coal from the Pittsburgh bed came from the American Zinc and Chemical Company's mine at Langeloth. A carbonization test in an 1800 c. c. retort gave a yield at the rate of 19.3 gallons of low-temperature tar per ton. This is probably a little low as the retort developed a slight leak during the test.

Westmoreland County.

The stratified rocks, appearing at the surface in Westmoreland County, belong to the Devonian, Mississippian, Pennsylvanian, and Permian series. The Pottsville, Allegheny, Conemaugh, and Monongahela, as well as the lowermost beds of the Washington formation, are all represented in the county.

The coals of the county have fixed-carbon percentages, computed on a pure coal basis, ranging from 58 in the western to 80 in the eastern part, with the major area lying between 60 and 65. Cannel coals and shales rich in volatile matter, therefore, would be expected to occur only in the western portion of the county.

Samples No. 102 and 104, inclusive, from the Lower Freeport horizon have already been described under Armstrong County in connection with the occurrence of cannel shale in the vicinity of Kiskiminetas Junction.

Samples No. 105 to 107, inclusive, likewise have been described under Allegheny County in connection with the cannel shale deposit associated with the thick Freeport coal in the northeastern part of that county.

Sample No. 108 was obtained from a layer of cannel shale, varying from 0 to 12 inches in thickness, which is associated with the Upper Freeport coal in the Darlington Coal Mining Company's mine at Darlington, in Ligonier Township. It yielded at the rate of 11.3 gallons of oil per ton.

Samples from outside Pennsylvania.

Samples 109 to 122, inclusive, were obtained from localities outside of the State and are introduced for the sake of comparison.

Conclusions.

During the summers of 1918 and 1920 the writer visited practically every locality in the State, in which cannel coal or shale or any other carbonaceous shale, which might prove to be an oil shale offering possibilities as a source of oil in the future, has been reported to occur. The deposits have been examined, samples taken and tested in the laboratory. This investigation has shown that Pennsylvania has no large deposits similar to the oil shales at the Devonian-Mississippian horizon in Ohio, Indiana, Kentucky, and Tennessee, or in the Green River formation of Colorado, Utah, and Wyoming. The many small deposits of cannel coal and shale of western Pennsylvania resemble these deposits rather closely as far as quantity and character of the oil which they yield on low-temperature carbonization, is concerned: but unfortunately, with the exception of the one occurrence at the Upper Freeport horizon in northeastern Allegheny County, none of them are very extensive. While there always is the possibility of discovering other similar deposits in the area of high volatile coals west of the 65 iso carb line, particularly in the Allegheny formation to which most of the cannel coal and shale occurrences of the State are confined, and especially in places where this formation is covered by overlying strata and does not crop at the surface, it is not likely that such shales are present in sufficient quantities to support any very large oil-shale industry in the future.

Before attempts are made to erect plants to recover oil from cannel coals and shales from any particular deposit, too much stress cannot be laid on the necessity of first making careful and thorough investigations of the extent of the deposit, and the quantity and character of the oil which the material will yield. The deposits are so erratic in these respects that careful prospecting, preferably by rather close core drilling, will be necessary to obtain the essential data to warrant spending any very large sums of money for the erection of the required plants to treat them.

With respect to the establishment of an industry, based upon low-temperature carbonization of bituminous coal, however, the situation is entirely different. Pennsylvania has enormous reserves of bituminous coal suitable for such treatment. An inspection of the map, figure 3, on page 43 shows that most of the bituminous coal area of Western Pennsylvania lies west of the 2.5 fuel ratio boundary and, therefore, contains coals suitable for low-temperature carbonization from the stand-point of by-product yield. Much of this coal is also suitable for metallurgical coke and gas manufacture and is already being drawn upon heavily for this purpose, with all indications that the demand from these industries will be still greater in the future. In 1918, the bituminous coal consumed in the manufacture of coke and coal gas in the State amounted to about 23 per cent of the total production of bituminous coal.

There is no reason why the enormous quantities of bituminous coal that are now being burned in the raw state for steam raising purposes and domestic use, cannot first be subjected to low-temperature carbonization, and eventually this will probably be done. In this way a fuel will be obtained in many respects superior to raw coal, the smoke nuisance of cities will be abated, and valuable by-products will be recovered, which will aid greatly in supplementing a waning petroleum supply.

CHAPTER VI.

METHODS OF TESTING COALS AND SHALES.

Sampling.

Representative samples, weighing from 15 to 40 pounds, were collected in the field. Each sample was taken wherever possible by cutting a narrow channel perpendicular to the bedding plane of the deposit. In the case of the ordinary coals the cut was made two inches deep and six inches wide. In the case of the cannel coals and shales a somewhat wider and deeper cut had to be made because of the difficulty of breaking these materials off from the face in small pieces. The only exceptions to the above procedure arose when the deposits themselves were inaccessible and it became necessary to sample dumps. All samples were shipped to the laboratory in canvas bags.

Crushing.

In the laboratory the samples were reduced by means of a small jaw crusher and rolls to pass through a 4-mesh screen. This size of material was used for both the carbonization and the ammonia-yield tests. By means of a Jones riffle sampler a 100-gram sample was cut from each field sample. Each 100-gram sample was crushed to 60-mesh in a small Abbe porcelain pebble mill and set aside in a rubber stoppered glass bottle, to be used later for making proximate analyses and nitrogen and sulphur determinations.

Carbonization tests.

Three types of retorts were employed in making the carbonization tests: namely, the United States Bureau of Mines oil shale assay retort, developed by L. C. Karrick of the Inter-mountain station of the Bureau; and an 1800-c. c. and a 3500-c. c. capacity vertical retort, designed by the writer.

U. S. Bureau of Mines oil shale assay retort.

The retort[1], recommended by the Bureau of Mines as a simple device for field and laboratory use where rapid assays of oil shales are desired with results of duplicate test agreeing within 1 or 2 per cent, consists essentially of a one-pint capacity cast iron amalgam retort with a ¼ inch street ell screwed into the lid, to which in turn is attached a 20-inch length of ¼ inch galvanized pipe, to the other end of which a tee is affixed. To the lower end of the tee there is attached a ¼ by 3 inch galvanized pipe nipple, cut at a 45° angle on the plain end. The nipple leads into a graduated glass cylinder of 100-c. c. capacity through a one-hole cork. 36 inches of 5/16 inch glass tubing are attached to the upper end of the tee by means of another one-hole cork.

The apparatus was assembled as shown in figures 12 and 13. The retort was enclosed in a

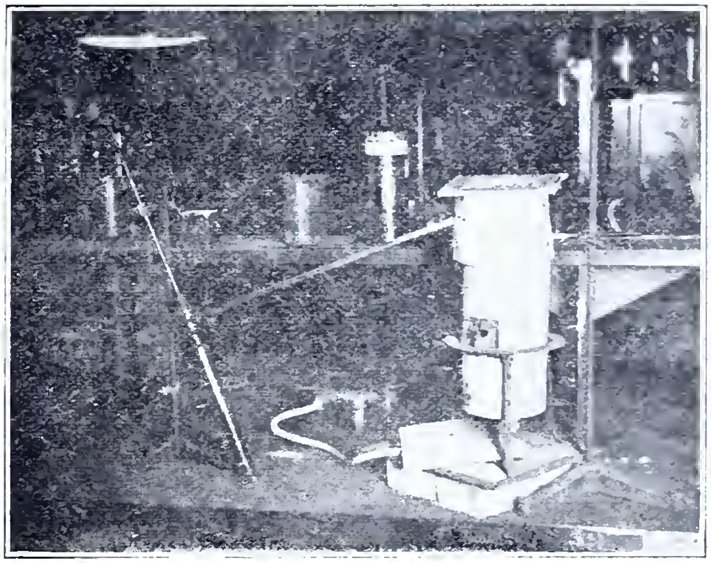
Fig. 12. U. S. Bureau of Mines oil shale assay retort.

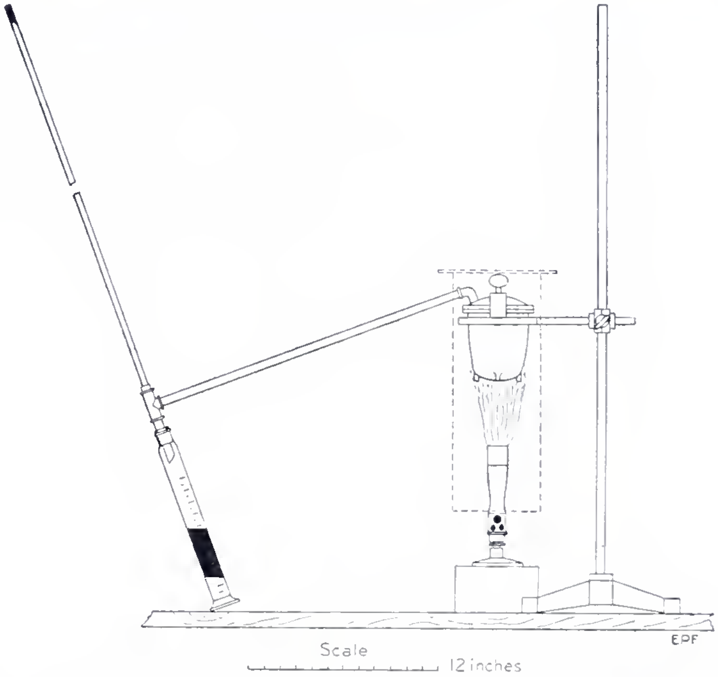

Fig. 13. Diagram showing U. S. Bureau of Mines oil shale assay retort.

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[1] Karrick, L. C. A convenient and reliable retort for assaying oil shales for oil yield. U. S. Bureau of Mines Reports of Investigations, Serial No. 2229. 1921.

cylindrical asbestos-board jacket with about one-quarter of an inch clearance at the sides and enough clearance on top for the clamp screw. Notches were cut in the jacket for ring support and delivery tube. A cover of asbestos board with a 1¾ inch hole at the center was provided to reflect heat downward against the retort lid so that oil would not condense on its inner side and drip into the shale, thus causing losses by secondary distillation. The contact surfaces of the lid and the top of the retort were carefully ground together, using fine carborundum powder, so as to form a gas-tight fit. A gasket, was used which consisted of a single thickness of asbestos paper coated with a paste of graphite and glycerin. A paste of pulverage litharge and glycerin was used on the pipe joints. The top and bottom connections of the tee with the glass tube and the graduate were also sealed with the same mixture. Heat was applied by means of a No. 3, 25-mm. diameter Meker burner, using natural gas as fuel.

Approximately 400 c. c. of shale, crushed to pass a 4-mesh screen, filled the retort level full. This quantity was weighed and placed in the retort. After the lid had been fitted carefully in place and the jacket and lid adjusted, the burner was started, using a very small flame. The graduated cylinder and reflux condenser were then attached. The initial flame was adjusted so that about 45 minutes elapsed before the first drops of oil appeared. After two or three c. c. of oil had accumulated, the flame was doubled in size and increased thereafter about an equal amount every 20 to 40 minutes. The rate of accumulation of the oil was kept as nearly uniform as possible and adjusted so that the distillation continued over a period of about two hours. Care was taken not to have the distillation so rapid that the condenser capacity would be exceeded. In such a case oil would appear in the upper portion of the glass tube reflux condenser and some would be lost at the top. After oil had ceased to come off, the lower part of the retort was brought to a dull red heat. The iron pipe leading from the retort was finally warmed slowly so as to drain it thoroughly.

The graduated cylinder was then removed and a glass stopper inserted. The cylinder was warmed in water heated to 60° C. so that the oil was brought to as fluid a condition as possible in order to permit complete separation of it from the water of the shale which likewise had distilled and condensed. The graduate was revolved rapidly between the palms of the hands while still warm to facilitate the formation of a good meniscus between the oil and the water. After allowing the contents to cool to room temperature, the volumes of oil and water were read. The contents of the graduate were then poured into a separatory funnel, warmed again, and the water drained off. The oil was placed in a well corked bottle and set aside for specific gravity determinations. The yield of oil per ton of 2,000 pounds was calculated by means of the following formula:—

$$\text{Gallons of oil per ton} = \frac{\text{Cubic centimeters of oil x 239.7}}{\text{Grams of shale used in retort}}$$

The specific gravities of the oils were determined by means of a 25 or 10-c. c. Geissler's specific gravity bottle fitted with ground-in thermometer and stoppered capillary tube, or a 2-c. c. Gay-Lussac's bottle with perforated stopper. The choice of these bottles depended upon the volume of oil available. The "water-equivalents" of the specific gravity bottles at 60° F. (15.56° C.) were determined previously and the specific gravities of the oils were taken either at that temperature or at 25° C.

In each of the above tests the yield of oil and of ammoniacal liquor in gallons per ton, 2,000 pounds, of shale, the specific gravity of the oil, and the weight of the spent material. or residue, were determined.

This type of retort was found to work very satisfactorily on all cannel coals and shales and oil shales tested. However, it cannot be used with bituminous and semi-bituminous coals that coke, for these expand on heating and soon choke the outlet.

1800 and 3500 c. c. capacity retorts.

In order to obtain quantities of oil sufficiently large to fractionate from one, or, at the most, two runs, and to test ordinary bituminous and semi-bituminous coking coals, a larger retort was required. A vertical cylindrical type 4 inches in diameter, was chosen. The first retort of this type constructed had an inside depth of 10 inches and held 1800 c. c. of coal or shale. It was made from a piece of 4-inch wrought-iron pipe 10 inches long, threaded at both ends. A cast iron cap was screwed onto the lower end and a heavy faced cast iron flange onto the upper end. Both of the joints were welded with an oxy-acetylene torch. A faced cast iron blind flange, with holes for an outlet pipe and the insertion of a base metal thermocouple, was used as a cover. It was attached to the flange of the retort by means of eight bolts. The retort was set in a fire brick furnace, heated by means of two Bunsen blast lamps. After about 45 runs had been made this retort developed a slight leak along the lower welded joint and had to be discarded.

A longer retort of the same type was then adopted. This also had an inside diameter of 4 inches and a length of 18 inches instead of 10. The main body of this retort was cast in one piece. The walls were $\frac{5}{8}$ inch thick. The top was a flange 1 inch thick and 10 inches in outside diameter, with eight holes to accommodate the bolts used to attach the faced cast iron blind flange of the 1800 c. c. retort. This blind flange was used as a cover for the new retort. The new retort held 3500 c. c. of coal or shale.

Figure 14 shows the manner of setting up the apparatus, both for the 1800 and 3500 c. c. re-

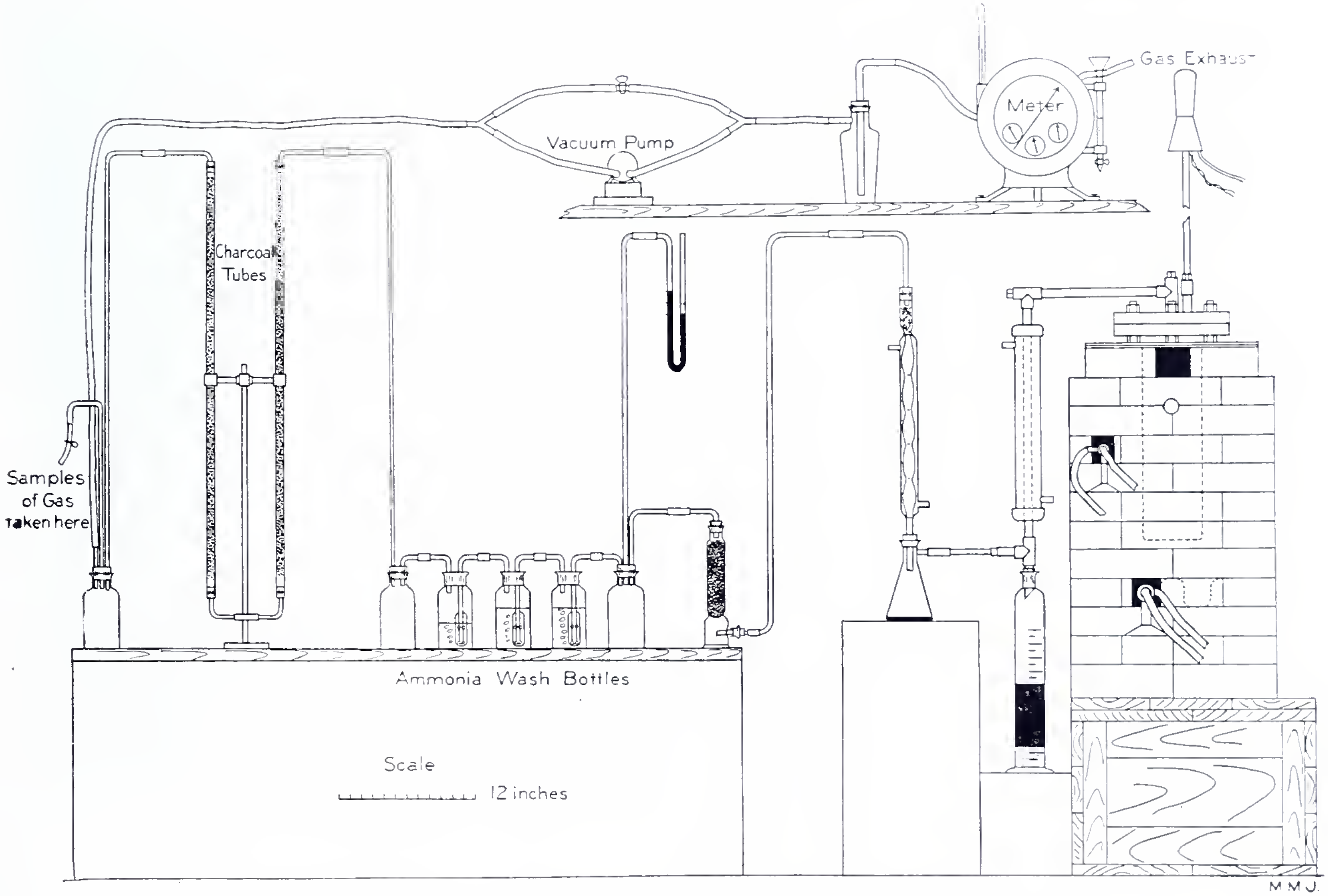

Fig. 14. Diagram showing 3500 c. c. retort and accompanying apparatus.

torts. Plate VI shows the appearance as installed in the laboratory. The body of the retort was set in a firebrick furnace of circular cross-section on the inside. The furnace was heated by means of four blast lamps, two on each side. For the lower two openings, small Fletcher blast furnace burners were used. The flames of these entered the furnace below the bottom of the retort. For the upper two openings Bunsen blast lamps were employed. The flames from these impinged on the inside walls of the furnace opposite the middle of the retort. The top of the furnace was covered by a sheet of ¼ inch asbestos board and a piece of sheet iron. In these were holes just large enough to admit the body of the retort, which was so arranged that it could be lifted into and out of the furnace. During carbonization tests another sheet of ¼ inch asbestos board was placed over the top of the cover with a notch cut in it for the delivery tube and the thermocouple tube.

A threaded hole was drilled through the center of the blind flange cover to receive a short ½ inch nipple, through which the vapors from the retort escaped. One inch from the center another similar hole was drilled and tapped to receive a short ⅝-inch nipple, through which the thermocouple was introduced into the retort. A gasket was used between the cover and the flange of the retort. This gasket consisted of two thicknesses of asbestos paper coated with a paste of graphite and glycerin.

For determining temperatures inside the retort, a base metal thermocouple of the pyod type was used. It was equipped with an auxiliary compensator couple and connected to a Wilson-Maeulen No. 33 portable indicator. The lower portion of the pyod rod was threaded and screwed into a

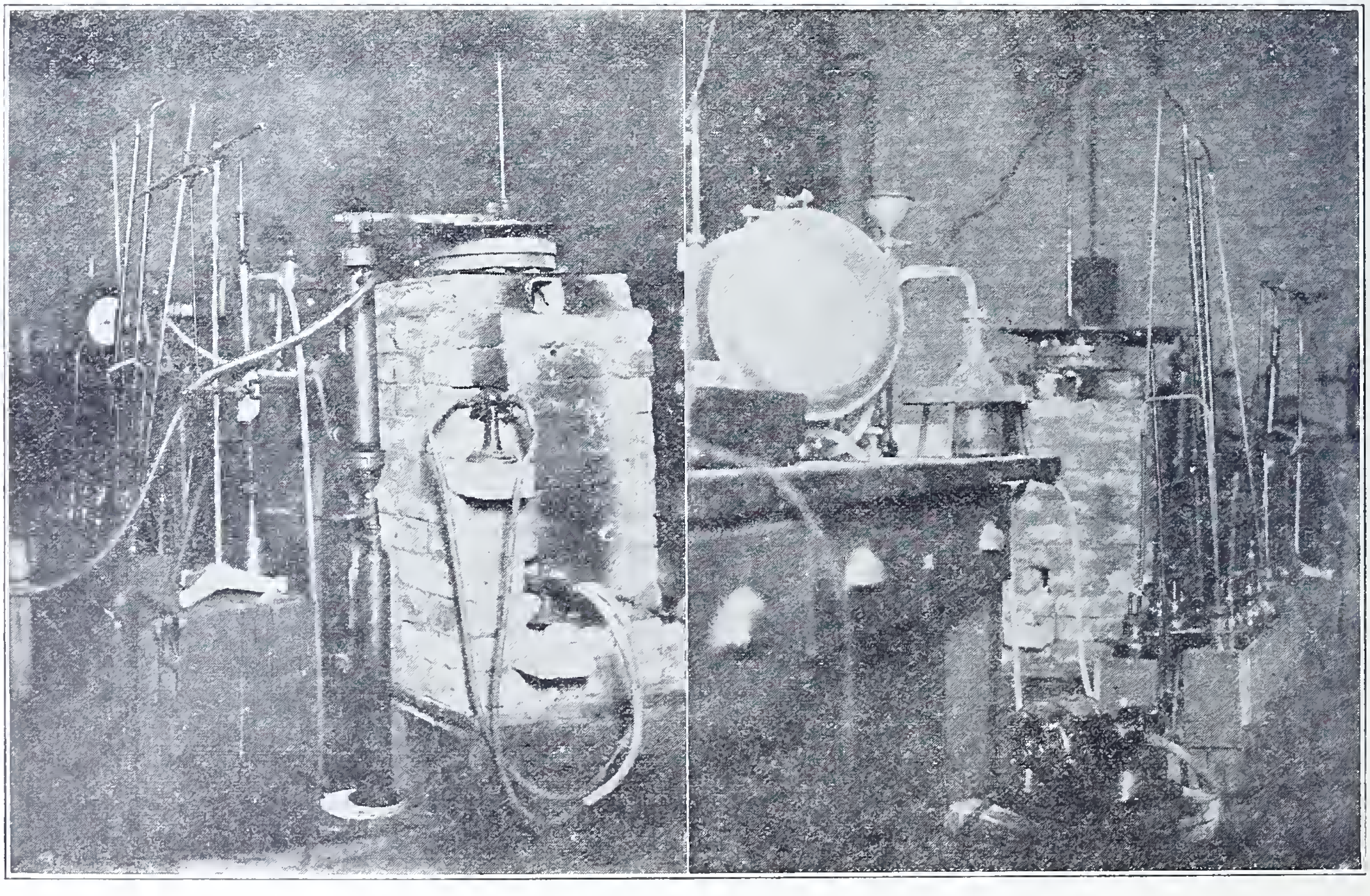

PLATE VI. Views showing appearance of 3500 c. c. retort and accompanying apparatus as set up in laboratory.

reducer attached to a short ⅝-inch nipple in the cover by means of a sleeve. In this way a gas tight connection was obtained. The thermocouple rod extended 4¾ inches into the retort. Its end just entered the upper part of the coal or shale charge.

To the short ½-inch nipple at the center of the cover a tee was attached. The tee was fitted with a plug at the upper end so that in case the vertical outlet from the retort became clogged, the tee could be opened and the outlet cleared. A horizontal iron pipe 10 inches long and ½ inch in diameter, covered with asbestos paper, was attached to the side opening of the tee. Another tee was attached to it at the other end. This tee, also, was fitted with a plug opposite the pipe so that in case the latter became clogged, the plug could be removed and the outlet cleared. To the lower end of the tee (side outlet) a vertical brass pipe ½ inch in diameter and 20 inches long was attached. This was surrounded by a jacket made from a piece of 2-inch pipe with caps at either end through which holes had been drilled to admit the brass tube. Cold water was kept circulating through this jacket while the carbonization tests were in progress. A third tee was attached to the lower end of the brass pipe. Into the side outlet of this tee a rubber stopper was inserted fitted with a ⅜-inch glass tube leading to the side tube of a 500 c. c. Erlenmeyer flask. A ½-inch pipe nipple, cut off at 45° at its lower end, was attached to the bottom of the tee. This was connected through a cork with a 1000 c. c. graduated cylinder, in which most of the oil, as well as the ammoniacal liquor collected. All pipe threads were coated with a paste of fine graphite and glycerin and screwed gas tight.

A vertical Allihn reflux condenser was attached to the Erlenmeyer flask. The condenser was 16 inches long, had five bulbs, and was cooled by a stream of cold water. Only a small quantity of oil accumulated in the latter condenser. A 5/16 inch glass tube was used to lead the uncondensed gases from the top of the refux condenser to the bottom of a 10-inch tower, which was filled with iron "jack" chain. From the top of the tower the gasses passed through another glass tube to a 500 c. c. "safety" bottle. A U-shaped mercury pressure gauge open to the atmosphere was attached to this bottle.

From the "safety" bottle, the gases next passed through three Allihn double action 500 c. c. gas washing bottles, containing twice normal (2N) sulphuric acid solution, 250 c. c. in the first two and 200 c. c. in the third. After leaving the gas washing bottles, the gases were next passed through another 500 c. c. "safety" bottle and then through two vertical tubes 3 feet long and ⅝ inch in diameter. These tubes were filled with 8 to 14-mesh Dorsite 40-minute activated charcoal. Each tube held 120 grams of charcoal.

From the charcoal tubes the path of the gases lead through another 500 c. c. bottle, from which the samples of gas for analysis were taken. Then the gases passed through a Cenco rotary, electrically-driven vacuum pump, through a 500 c. c. Erlenmeyer flask, and finally through a 100 cubic foot American wet gas meter. A shunt was provided around the vacuum pump so that the latter could be shut off when samples of gas were taken.

In charging the retort, about 3500 c. c. of coal or shale (which had previously been crushed to pass a 4-mesh screen) were weighed and put into the retort. A tube one inch in diameter and 18 inches long, made of 12-mesh iron screen, was placed along the center line of the charge. A sheet iron disc 4 inches in diameter provided with holes for the screen tube and thermocouple rod was placed on top of the charge. A space of about 4½ inches remained between the disc and the cover of the retort.

The retort was heated at a rate so that the indicator showed the following temperatures after the specified number of hours:

Rate of heating retort.

Hours	°F.	Hours	°F.	Hours	°F.
½	150	3	750	5½	1000
1	300	3½	800	6	1100
1½	450	4	850	6½	1200
2	600	4½	900 (482° C)	7	1300
2½	700	5	950	7½	1400 (760° C)

The retort was kept at 1400° F., usually ½ hour, until gas ceased to come off.

The thermocouple projected only into the upper portion of the charge. The lower part of the charge, particularly during the early stages of the test, was at a somewhat higher temperature. It is impossible, by means of a gas fired furnace of the type employed, to keep the temperature uniform throughout the entire length of the retort. The outside of the lower part of the retort was coated with a thin layer of "Adamant" fire brick cement to protect it from excessive oxidation. In the case of some of the tests, the temperature was carried only to 900° F. (482° C.). It was found that where duplicate tests on the same material were made, carrying the temperature to 1400° F. (760° C.) in one instance and 900° F. (482° C.) in the other, the volume of oil or tar obtained was practically the same in each case but the gas and ammonia yield were considerably increased by continuing to the higher temperature. Carbonization was conducted under a slight vacuum, the pressure at the mercury gage being kept at about 2 inches less than that of the atmosphere.

After a test had been completed, water previously heated to the boiling point, was circulated through the condensers so as to thoroughly drain the apparatus of oil. The 1000 c. c. graduated cylinder, containing the bulk of the oil or tar and the ammoniacal liquor, was removed. What little oil had accumulated in the Erlenmeyer flask was added to that in the graduated cylinder. A glass stopper was inserted into a cylinder and the cylinder and contents were warmed in water heated to 60° C. so as to facilitate the separation of the oil or tar and water. The cylinder was revolved rapidly between the palms of the hand so as to aid in the formation of a good meniscus between the two, cooled to room temperature and the volumes read. The contents of the cylinder were then poured into a separatory funnel, again warmed, and allowed to stand over night. The oil or tar and ammoniacal liquor were then separated. The oils and the low-temperature tars obtained from ordinary bituminous coal floated on top of the ammoniacal liquor, although an occasional small globule of the tar would separate and settle to the bottom of the water. Determinations of the water content of the oils and tars showed that very good separations were made.

The specific gravities of the oils and tars were determined by means of a 50 c. c. Geissler specific gravity bottle, fitted with ground-in thermometer and stoppered capillary tube. These were taken at either 15.56 or 25° C. and compared with water at 15.56° C. (60° F.).

The volume of oil or tar and ammoniacal liquor per ton were calculated by means of the following formulas:—

$$\begin{array}{c}\text{Gallons of oil per ton (2000 pounds)}\\ \text{of coal, shale, etc.}\end{array} = \frac{\begin{array}{c}\text{Cubic centimeters of oil}\\ \text{x 239.7}\end{array}}{\begin{array}{c}\text{Grams of coal or shale}\\ \text{used in retort}\end{array}}$$

After the retort had cooled sufficiently, the spent material was removed and weighed. The yield per ton was then computed.

The 120 grams of 8 to 14-mesh Dorsite 40-minute activated charcoal served to adsorb light oil vapors from the gases evolved, which failed to liquefy in the condenser system employed. The light oil was recovered by mixing the charcoal with about an equal volume of glycerin and distilling in a tar still up to 200° C., using a 16-inch inclined water-cooled condenser. Its specific gravity was determined by means of a 25 or 10 c. c. Geissler specific gravity bottle with ground-in thermometer and stoppered capillary tube, or a 2 c. c. Gay-Lussac bottle with perforated stopper. Which of these was used depended upon the volume of oil available.

A portion of the ammonia produced from the nitrogen in the coal or shale during the carbonization process was recovered in the ammoniacal liquor which condensed with the oils or tars. The balance was fixed as ammonium sulphate in the 700 c. c. of twice normal sulphuric acid solution used in the gas washing bottles. The two solutions were analyzed separately. Each was first diluted to 1000 c. c.. By means of a pipette, 25 c. c. were measured in duplicate into two 800 c. c. Kjeldahl flasks. Each aliquot portion was diluted with 250 c. c. of water. Twice normal (2N) sodium hydroxide solution was added, 10 c. c. in the case of the ammonical liquor and 30

c. c. in the case of the sulphuric acid wash water. The flask was then connected through a Kjeldahl bulb tube to a 16-inch vertical water cooled condenser of the Allihn type with five bulbs, the lower end of which extended into 75 c. c. of standardized one-fifth normal sulphuric acid solution. After the ammonia had been distilled off, the excess sulphuric acid was titrated with one-fifth normal sodium hydroxide solution and the amount of acid which had been neutralized by ammonia was determined. From this was computed the quantity of ammonia present in the solution.

A very small percentage of the nitrogen in the ammoniacal liquor and sulphuric acid wash water is present in the form of pyridine compounds instead of ammonia. A correction in the amount of ammonia as determined above was made after the pyridine content had been determined. For the pyridine determinations, 100 c. c. of the ammoniacal liquor or sulphuric acid wash water, which had previously been diluted to 1000 c. c., were measured into an 800 c. c. Kjeldahl flask by means of a pipette. This solution was further diluted with 150 c. c. of water. Twice normal sodium hydroxide solution was added; 30 c. c. in the case of the ammoniacal liquor and 100 c. c. in the case of the sulphuric acid wash water. The pyridine and ammonia were distilled off and caught in 50 c. c. of normal sulphuric acid solution. The latter was then carefully neutralized by means of normal sodium hydroxide solution. The neutral solution was poured into an 800 c. c. Kjeldahl flask, and 5 c. c. of normal sodium hydroxide solution were added. The pyridine and some ammonia were distilled off and caught in 10 c. c. of normal sulphuric acid, to which 50 c. c. of water had been added. This distillate was again placed in an 800 c. c. Kjeldahl flask. Then were added 100 c. c. of sodium hypobromite solution (made by dissolving 100 grams of caustic soda in 1000 c. c. of distilled water, cooling, and adding 25 c. c. of bromine). The flask was violently shaken.[1] The pyridine was then distilled off into 25 c. c. of one-fifth normal sulphuric acid solution. The excess acid was titrated with one-fifth normal sodium hydroxide solution and the volume of acid neutralized by the pyradine was determined, from which the quantity of pyridine present was calculated.

From the data thus obtained, the total ammonia present in the ammoniacal liquor and in the sulphuric acid wash water was determined. The recovery of nitrogen per ton in the form of ammonia or ammonium sulphate was calculated, as was also the per cent of nitrogen in the coal or shale which was converted into ammonia during the carbonization process and which escaped decomposition in the retort.

The total sulphur present in the ammoniacal liquor was also determined. 50 c. c. of the liquor (which had previously been diluted to 100 c. c.) were added drop by drop from a burette into an Erlenmeyer flask which contained 15 c. c. of concentrated hydrochloric acid, 35 c. c. of distilled water, and an excess of bromine. After the addition of 10 c. c. of a 10 per cent solution of sodium chloride, the solution was evaporated to dryness in a porcelain dish over a sand bath. About 5 c. c. of concentrated hydrochloric acid were added to the residue, which was then repeatedly extracted with boiling water, filtered, and the volume made up to 200 c. c. by dilution with water. The solution was then boiled and the sulphur precipitated as barium sulphate by adding drop by drop from a burette 25 c. c. of a 10 per cent solution of barium chloride. The solution containing the precipitate was kept at a temperature just below boiling for two hours. It was filtered the next day. After ignition in a porcelain crucible, the barium sulphate was weighed. From the result thus obtained, the quantity of sulphur present in the ammoniacal liquor was calculated.

The volume of permanent gases was measured by passing them through a 100 cu. ft. American gas meter. The gas temperature at the meter and the barometric pressure were observed every half hour. By means of a table of factors the volume was equated to 60° F., 30 inches of mercury pressure, and saturation with moisture. The yield per ton (2000 pounds) of shale or coal was then calculated.

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[1] Houghton, A. C. The estimation of pyridine in aqua ammonia. Jour. of Indus. and Eng. Chem., Vol. 1. pp. 698-700. 1909. The sodium hypobromite oxidizes the ammonia but has no action on the pyridine.

Samples of the gases were taken when temperatures of 650°, 950°, and 1250° F. were indicated on the recorder to which the thermocouple was connected. In those tests where the operation was stopped at 900° F., the samples were taken at 600° and 900° F. The samples were analyzed according to the methods of technical gas analysis outlined by White.[1] In the gas analyses a Hempel gas burette with glass stop cocks and water jacket was employed for measuring volumes. Carbon dioxide was determined by absorption in a solution of sodium hydroxide made up of 50 grams of caustic soda per 150 c. c. of water. This solution was stored in a simple Hempel gas pipette. Three minutes were allowed for absorption. Hydrogen sulphide and sulphur dioxide which may be present in the gas were also absorbed by this solution. Unsaturated hydrocarbons were removed by means of saturated bromine water kept in a compound Hempel burette with a double bulb for the bromine water; the upper bulb was filled with glass beads. Water was kept in the second bulb. About ten minutes were allowed for the absorption. Afterwards, in order to remove bromine vapors, the gas was allowed to stand over a caustic soda solution for one minute before the volume was measured. Oxygen was determined by means of an alkaline pyrogallate solution made up of equal volumes of one part of pyrogallol in three of water and one part of potassium hydroxide in two of water. A fresh solution was prepared every four weeks. It was stored in a double pipette, the second bulb of which was filled with water. Five minutes were allowed for the absorption of the oxygen, the apparatus being frequently shaken. Carbon monoxide was determined by means of a cuprous chloride solution, made by dissolving 150 grams of cuprous chloride in one liter of concentrated hydrochloric acid of specific gravity 1.12. Two double pipettes were used. Concentrated hydrochloric acid was kept in the second bulb and strips of metallic copper were placed in the first bulb with the cuprous chloride solution. The gas was kept in each pipette for three minutes. A record was kept and after the second pipette had absorbed 10 c. c. of carbon monoxide, it was used as the first pipette and a new solution was placed in the other. Methane and hydrogen were determined in a Hempel explosion pipette, equipped with a leveling bulb filled with mercury. Nitrogen was determined by difference.

Proximate analyses of the coal and shale samples tested in the 1800- and 3500- c. c. retorts, and of the spent material from the 3500- c. c. retort were made according to the methods recommended by the U. S. Bureau of Mines.[2] The uncorrected ash as determined has been reported in each instance; therefore errors of considerable magnitude may occur in some of the shale analyses, due to dehydration of clayey substances, the oxidation of pyrite, and the decomposition of calcium and ferrous carbonates.

The nitrogen content of the above mentioned samples was determined by the Kjeldahl-Gunning method.[3] One gram of the air-dried material pulverized to pass a 60-mesh screen, was digested with 30 c. c. of concentrated sulphuric acid, 0.5 gram of metallic mercury, and 5 grams of potassium sulphate in a 500 c. c. Kjeldahl flask until the carbon had been completely oxidized and all the nitrogen had been converted to ammonium sulphate. Boiling was continued for two hours after the solution had reached the straw-colored stage. A crystal of potassium permanganate was then added after the solution had been cooled a few minutes, so that flashing would not take place. After cooling, the solution was diluted to about 200 c. c. with cold water; 25 c. c. of potassium sulphide solution (40 grams of potassium sulphide per liter) were added to precipitate the mercury, and 100 c. c. of saturated sodium hydroxide solution were carefully poured down the side of the flask to make the solution alkaline. One to two grams of granular zinc and a little paraffin were added to prevent bumping and foaming, and the flask was at once connected through a Kjeldahl connecting bulb with a condenser and the ammonia distilled off into 25 c. c. of one-fifth normal sulphuric acid. The distillation was continued until about 200 c. c. of distillate had passed over. The excess acid was then titrated with N/5 sodium hydroxide solution, using cochineal as an indicator. The nitrogen content of the sample was computed from the volume of sulphuric acid solution neutralized by the ammonia formed from it. For each new lot of chemicals used, a blank determination was run in which one gram of pure saccharose was substituted for the coal or shale sample. The nitrogen shown by this blank determination was deducted from the nitrogen found in each determination made with the same chemicals. It was found that the correction factor was almost negligible.

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[1] White, Alfred H. Technical gas and fuel analysis, 1st edition, New York, 1913.

[2] Fieldner, Arno C. Notes on the sampling and analysis of coal. U. S. Bureau of Mines, Technical Paper, 76, pp. 15-17, 1914.

[3] Stanton, Frederick M. and Fielder, Arno C. Methods of analyzing coal and coke. U. S. Bureau of Mines, Tech. Paper 8, pp. 24-25, 1913.

Sulphur was determined only in those samples treated in the 3500 c. c. retort and in the residues from those tests. The well known Eschka method was employed.[1]

CHAPTER VII.

RESULTS OF CARBONIZATION TESTS.

During the present investigation, carbonization tests were made on 122 samples. The numbers here given will identify the samples in the tables beginning on p. 88 and are used also to indicate localities on the maps.

Allegheny County

1. Cannel shale from roof of Upper Freeport coal. Diamond Coal and Coke Company's Oakmont No. 1 mine, at Barking Station, Plum Township.

2. Bituminous coal. Upper Freeport bed. Creighton mine of Pittsburgh Plate Glass Company, at Creighton, East Deer Township.

3. Cannel shale from roof of Upper Freeport coal. See 2.

4. Cannel shale from roof of Upper Freeport coal. (above No. 3). See 2.

5. Bone from Upper Freeport coal. Bessemer No. 2 mine of Republic Iron and Steel Company. 1 mile south of Russellton, West Deer Township.

6. Cannel shale from roof of Upper Freeport coal. See 5.

7. Bone from Upper Freeport coal. No. 1 mine of Superior Fuel Company. 2/3 mile northeast of Russellton, West Deer Township.

8. Cannel shale from roof of Upper Freeport coal. See 7.

9. Cannel shale from roof of Upper Freeport coal. (above No. 8) See 7.

10. Cannel shale from roof of Upper Freeport coal. No. 1 or Benjamin mine of Ford Collieries Company. 1/3 mile northwest of Curtisville. West Deer Township.

11. Cannel shale from roof of Upper Freeport coal. No. 2, or Francis mine of Ford Collieries Company. 2/3 mile west of Culmerville, West Deer Township

12. Cannel shale from roof of Upper Freeport coal. No. 3 or Berry mine of Ford Collieries Company, at Bairdford. West Deer Township.

13. Carbonaceous shale. Duquesne horizon of Conemaugh formation. From outcrop. Sample in weathered condition. On East Fork of Sandy Creek about ½ mile above White Ash (Sandy Creek Station), Penn Township.

14. Carbonaceous shale. Duquesne horizon of Conemaugh formation. Represents least weathered material obtainable from outcrop. Along Beaver and Pittsburgh road, ½ mile southeast of Bayne, Franklin Township.

15. Carbonaceous shale. From roof of Pittsburgh coal. Cut along Aylesboro Avenue, near Murray Avenue, Pittsburgh.

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[1] Stanton, Frederick M. and Fieldner, Arno C. op. cit. pp. 18-19.

Armstrong County.

16. Bituminous coal. Lower Kittanning bed. Pine Run Coal Company's No. 7 mine. 1 mile south of New Bethlehem, Mahoning Township.

17. Cannel shale. From roof of Middle Kittanning coal. Christman and Dewey's country bank, at Lacy's Store along Hart's Run, Bradys Bend Township.

18. Bituminous coal. Upper Kittanning bed. Pine Run Coal Company's No. 9 mine. 1½ miles south of New Bethlehem, Mahoning Township.

19. Cannel coal. Upper Kittanning bed. See 18.

20. "Curly" or "bird's eye" cannel coal. Upper Kittanning bed. See 18.

21. Cannel shale from Upper Kittanning bed. See 18.

22. Carbonaceous shale from roof of Upper Kittanning bed. See 18.

23. Cannel coal from Upper Kittanning bed. From country bank on G. P. Gruver (formerly Schieck) farm, ¾ mile northeast of McWilliams, along Sugar Camp Run, Red Bank Township.

24. Cannel coal from Upper Kittanning bed. Average sample from dump of old Ganner mine. ⅓ mile north of Somerville, near head of Holder Run, Bradys Bend Township.

25. Carbonaceous shale above Upper Kittanning coal. From outcrop 1⅓ miles south of Adrian, along branch of Limestone Run, East Franklin Township.

26. Carbonaceous shale above Upper Kittanning coal. See 25.

27. Cannel shale below Upper Kittanning coal. See 25.

28. Bituminous coal. Lower Freeport bed. Prospect opening of Pine Run Coal Company, 1¼ miles south of New Bethlehem, Mahoning Township.

29. Cannel shale. Lower Freeport horizon. Average sample from dump of old Aladdin Company's mine, at Aladdin, Gilpin Township.

30. Cannel shale. Lower Freeport horizon. From outcrop at Schenley, Gilpin Township.

31. Cannel shale. Lower Freeport horizon. Average sample from dump of old North American Company mine. ½ mile southeast of Schenley, Gilpin Township.

32. Bituminous coal. Upper Freeport bed. Pine Run Coal Company's No. 10 mine. 1½ miles south of New Bethlehem, Mahoning Township.

33. Cannel shale from roof of Upper Freeport coal. See 32.

Beaver County

34. Bituminous coal. Lower Kittanning bed. Country bank of William Fairweather, at Industry, Industry Township.

35. Cannel coal. Upper Kittanning horizon. Paragon Coal and Coke Company's mine on Cannel Run, north of Cannelton, Darlington Township.

36. Cannel shale. Upper Kittanning horizon. Wistar Coal Corporation's mine on Cannel Run, north of Cannelton, Darlington Township.

37. Bituminous coal. Upper Kittanning horizon. Abandoned mine on Cannel Run, north of Cannelton, Darlington Township.

38. Cannel coal. Upper Kittanning horizon. See 37.

39. Cannel coal. Upper Kittanning horizon. See 37.

40. Cannel shale. Upper Kittanning horizon. See 37.

41. Cannel shale. Upper Kittanning horizon. Wistar Coal Corporation's mine on Cannel Run, north of Cannelton, Darlington Township.

42. Bony coal. Probably Upper Kittanning horizon. From outcrop along small run emptying into Beaver River, opposite Beaver Falls, Daugherty Township.

43. Bituminous coal. Upper Freeport bed. Keystone Drilling Company's mine. ½ mile north of Cannelton, Darlington Township.

44. Bituminous coal. Upper Freeport bed. Pittsburgh-Cannelton Coal Company's mine. ½ mile west of Cannelton, Darlington Township.

45. Bituminous coal. Probably Mahoning bed. Union Clay and Coal Company's mine. 1½ miles northwest of Cannelton, Darlington Township.

46. Cannel shale. Probably Brush Creek horizon. Country bank of Elmer E. Plugh. 2½ miles northeast of New Brighton, Daugherty Township.

47. Carbonaceous shale. Probably Brush Creek horizon. Sample taken from weathered outcrop. See 46.

48. Cannel shale. Brush Creek horizon. Country bank of Samuel Longnecker. 3¾ miles northeast of New Brighton, North Sewickley Township.

49. Cannel coal. Bakerstown horizon. Average sample from dump of old country bank of J. R. Peters. 1 mile east of Georgetown, Greene Township.

Blair County.

50. Carbonaceous shale. Burket horizon of Upper Devonian. Weathered sample from outcrop in excavation for the foundation of a house at East Altoona.

Butler County.

51. Bituminous coal. Brookville bed. Lower bench. Bessemer mine of Butts Cannel Coal Company, ½ mile northeast of Deegan, Venango Township.

52. Bituminous coal. Brookville bed. Upper bench. Bessemer mine of Butts Cannel Coal Company, ½ mile northeast of Deegan, Venango Township.

53. Cannel coal. Upper Kittanning horizon. Average sample from slack dump from old Annandale No. 1 mine of Butts Cannel Coal Company, at Deegan. Venango Township.

54. Cannel shale. Upper Kittanning horizon. Average sample from waste dump. See 53.

55. Cannel coal. Upper Kittanning horizon. From country bank of Myron Campbell heirs. 1½ miles southwest of North Washington. Washington Township.

56. Carbonaceous shale. Upper Kittanning horizon. See 55.

57. Cannel shale. Upper Kittanning horizon. From outcrop along creek near Shakeley School. 1½ miles southeast of Bruin, Parker Township.

58. Cannel coal. Probably Upper Kittanning horizon. Average sample from dump of propect opening on Jennings C. McCandless farm, along Swamp Run, Franklin Township, 1 mile west of Unionville.

59. Cannel shale. Probably Upper Kittanning horizon. See 58.

60. Cannel shale. Probably Upper Kittanning horizon. Average sample from dump of prospect opening on J. M. McBride farm, along Swamp Run, Franklin Township, 2 miles northwest of Unionville.

61. Cannel shale. Probably Upper Kittanning horizon. Sample from dump of old prospect opening along Swamp Run, 1¼ miles east of Isle, Franklin Township.

62. Cannel coal. Probably Upper Kittanning horizon. Country bank of G. W. Currie, 2 miles north of Nealeys, Worth Township.

63. Carbonaceous shale, above cannel coal. Probably Upper Kittanning horizon. See 62.

64. Cannel shale. Probably Upper Kittanning horizon. From dump of abandoned prospect opening, 1 mile northwest of Queen Junction, Clay Township.

65. Cannel shale. Upper Freeport horizon. Country bank on farm of John Marburger. 2 miles southeast of Evans City, Forward Township.

Center County.

66. Semi-bituminous coal. Lower Kittanning or B bed. Moshannon Coal Company's No. 11 mine, south of Philipsburg.

67. Canneloid semi-bituminous coal. Lower Kittanning or B horizon. See 66.

Clearfield County.

68. Canneloid semi-bituminous coal. Probably Lower Kittanning or B horizon. Cannel Crest mine of Woodland Cannel Coal Company, north of Woodland.

69. Canneloid semi-bituminous coal. Probably Middle Kittanning horizon. Sample from dump of abandoned country bank on Overly farm, north of Woodland.

70. Semi-bituminous coal. Probably Upper Kittanning horizon. Sterling Coal Mining Company's No. 2 mine. 2 miles southeast of Houtzdale. Woodward Township.

71. Canneloid semi-bituminous coal. See 70.

72. Canneloid semi-bituminous shale. See 70.

73. Carbonaceous shale. See 70.

74. Semi-bituminous coal. Lower Freeport or D horizon. Hartley No. 1 mine of J. Swires, north of Graham Station.

Fayette County.

75. Cannel shale. Redstone horizon. Weathered sample from prospect opening along outcrop. Northeast edge of New Geneva, Nicholson Township.

Greene County.

76. Cannel shale. Redstone horizon. From prospect opening on E. R. Gabler farm. ½ mile northwest of Greensboro, Monongahela Township.

77. Bituminous coal. Sewickley bed. Country bank on farm of S. I. Black. ¾ mile west of Greensboro, Monongahela Township.

78. Carbonaceous shale. Uniontown horizon. Weathered sample from outcrop along small run emptying into the Monongahela River, ¼ mile below Whiteley Creek, Monongahela Township.

79. Bituminous coal. Waynesburg bed. Moredock mine of American Steel Company, 1½ miles east of Waynesburg, Franklin Township.

80. Carbonaceous shale. Below Washington coal. Weathered sample from outcrop along Purman Run, at Waynesburg.

81. Carbonaceous shale. Above Washington coal. See 80.

82. Cannel shale. Below Upper Washington coal. From prospect opening on east side of Boyd Run, 2 miles above mouth, Washington Township.

Indiana County.

83. Cannel coal. Upper Kittanning horizon. Bicknell Brothers mine near head of Crooked Run, Grant Township, 3 miles south of Savan.

84. Cannel shale. See 83.

85. Bone from Upper Freeport bed. Jefferson and Clearfield Coal and Iron Company's No. 2 mine, at Ernest, Rayne Township.

86. Carbonaceous shale. Possibly Bakerstown horizon. Weathered sample from outcrop near head of small run flowing northward into Cowanshannock Creek, in South Mahoning Township, 1 mile east of Barnards.

Jefferson County.

87. Cannel shale. Roof of Lower Freeport coal. Jefferson Coal Company's No. 8 or Big Ben mine, at Coal Glen.

Lawrence County.

88. Cannel shale. Probably Upper Kittanning horizon. Average sample from dump at old abandoned country bank on Thomas M. Stewart farm. 1¼ miles southeast of Mountair, Little Beaver Township.

Luzerne County.

89. Anthracite. Hillman bed. Stanton No. 7 mine of Lehigh-Wilkes-Barre Coal Company, at Wilkes-Barre.

90. Canneloid anthracite from Hilman bed. Stanton No. 7 mine of Lehigh-Wilkes-Barre Coal Company, at Wilkes-Barre.

Lycoming County.

91. Semi-bituminous coal. "B" bed. Ralston Coal Company's mine on Red Run, just west of Ralston.

Mercer County.

92. Cannel shale. Probably Sharon coal horizon. Average sample from dump of abandoned prospect on southeast side of Neshannock Creek, ½ mile northeast of Leesburg Station, Springfield Township.

93. Bituminous coal. Brookville bed. Diamond No. 3 mine of the Scotch Hills Coal Company, 2 miles east of Grove City, Pine Township.

Sullivan County.

94. Semi-anthracite. Bernice or "B" bed. Northern Anthracite Coal Company's Murray mine, at Lopez.

Tioga County.

95. Semi-bituminous coal. Bloss bed. Bower Coal Company's mine, at Blossburg.

96. Carbonaceous shale. Cannel bed. No. 15 drift of Morris Run Coal Mining Company, at Morris Run.

97. Canneloid semi-bituminous shale. Cannel bed. No. 15 drift of Morris Run Coal Mining Company, at Morris Run.

Washington County.

98. Bituminous coal. Pittsburgh bed. Arden No. 2 mine of the Meadowland Coal Company. 1¼ miles northwest of Arden, Chartiers Township.

99. Bituminous coal. Pittsburgh bed. Ellsworth Collieries Company's No. 2 mine, at Ellsworth.

100. Coal washer refuse from Pittsburgh coal. Ellsworth Collieries Company's washer at Ellsworth.

101. Bituminous coal. Pittsburgh bed. American Zinc and Chemical Company's mine, at Langeloth.

Westmoreland County.

102. Cannel shale. Lower Freeport horizon. From outcrop along small run flowing northward into Kiskiminitas River. ¾ mile southeast of Kiskiminitas Junction, Allegheny Township.

103. Cannel shale. See 102.

104. Cannel shale. Lower Freeport horizon. Average sample from old dump of Lucesco Company's mine along Lucesco Hollow, ½ mile south of Kiskiminitas Junction, Allegheny Township.

105. Bituminous coal. Upper Freeport bed. Valley Camp No. 3 mine of Valley Camp Coal Company, along Pucketa Creek, 1 mile east of Parnassus, Lower Burrell Township.

106. Bone from Upper Freeport bed. See 105.

107. Cannel shale from roof of Upper Freeport bed. See 105.

108. Cannel shale from roof of Upper Freeport bed. Darlington Coal Mining Company's mine at Darlington, Ligonier Township.

Samples from other States.

109. Oil shale. Chattanooga (Upper Devonian) shale. Sample collected by Chas. R. Fettke from outcrop near Means post office, Montgomery County, Kentucky.

110. Oil shale. Chattanooga (Upper Devonian) shale. Sample received from S. E. Barnwell, taken from property of the Devon Oil Shale Products Company, about 1 mile east of Clay City, Powell County, Kentucky.

111. Oil shale. Chattanooga (Upper Devonian) shale. Sample collected by Chas. R. Fettke from the outcrop on Long Fork Creek, near Redboiling Springs, Macon County, Tennessee.

112. Oil shale. Nova Scotia. Received from Richard R. Hice, former State Geologist of Pennsylvania. Exact locality not known.

113. Oil shale. Green River formation. Representative sample taken by Chas. R. Fettke from the outcrop of a rich bed of shale, 1 foot thick, near the top of the cliff at the head of Cottonwood Gulch, northeast of Grand Valley, Garfield County, Colorado.

114. Oil shale. Green River formation. Representative sample taken by Chas. R. Fettke from the outcrop of a lean bed of shale, 40 feet thick. See 113.

115. Oil shale. Green River formation. Sample of crushed shale received from A. G. Fisher, taken from storage bin of Monarch Oil Shale Company, on Conn Creek, Garfield County, 12 miles north of De Beque, Colorado.

116. Oil shale. Green River formation. Small sample of rich, so-called "wurtzilite" shale, received from Lewis W. Leach. Taken from property of Colorado Carbon Company, at the head of Kimball Creek, Garfield County, north of De Beque, Colorado.

117. Oil shale. Green River formation. Sample of rich shale received from Joseph Bellis. Obtained near Grand Valley, Garfield County, Colorado.

118. Oil shale. Green River formation. Sample of rich shale received from Nile Hughel. Obtained near Watson, Uinta County, Utah.

119. Lignite. Fort Union beds of Eocene age. Sample received from Martin Olsen. Obtained near Kenmare, Ward County, North Dakota.

120. Lignite. Tertiary. Sample obtained from Donald W. Ross from Mississippi (exact locality not known).

121. Oil shale. Probably Miocene. Average sample taken by Chas. R. Fettke from dump at mine, Catlin Shale Products Company's property, 1½ miles southwest of Elko, Nevada.

122. Oil shale. Probably Miocene. Sample received from W. L. Sheeler. Obtained from property of Catlin Shale Products Company, 1½ miles southwest of Elko, Nevada.

Unless otherwise stated all of the samples listed were collected in the field by the writer.

A summary of the results of all the carbonization tests made on the samples just described, including yields of oil or tar and ammoniacal liquor in gallons per ton (2,000 pounds) of coal or shale, the specific gravities of the oil or tar, and the weight of the residue (pounds per ton), is given in the following table:—

Carbonization tests on coal and carbonaceous shale.

No. of sample	Character of sample	Locality	Oil or tar, gallons	Specific gravity of oil or tar	Ammoniacal liquor, gallons	Weight of residue, pounds	Retort used
		PENNSYLVANIA Allegheny County					
1.	Cannel shale, Upper Freeport	Barking Station	25.5	.9011	13.1	1,575	U. S. B. M.
2.	Bituminous coal, Upper Freeport	Creighton	24.8	.9796	16.9	1,368	1800 cc.
3.	Cannel shale, Upper Freeport	do.	29.6	.9217	11.1	1,529	U. S. B. M.
3.	do.	do.	30.4	.9226	12.5	1,479	1800 cc.
4.	Cannel shale, Upper Freeport	do.	13.4	.9185	11.3	1,719	U. S. B. M.
4.	do.	do.	15.7	.9318	10.7	1,653	1800 cc.
5.	Bone, Upper Freeport	Russellton, 1 mi. S.	10.9	.9850	17.2	1,667	U. S. B. M.
6.	Cannel shale, Upper Freeport	do.	26.4	.9197	11.1	1,580	U. S. B. M.
7.	Bone, Upper Freeport	Russellton, ⅔ mi. N. E.	16.3	.9829	15.7	1,622	U. S. B. M.
7.	do.	do.	18.1	.9828	15.2	1,574	1800 cc.
8.	Cannel shale, Upper Freeport	do.	34.7	.8968	9.5	1,485	U. S. B. M.
8.	do.	do.	36.7	.9006	12.2	1,427	1800 cc.
9.	Cannel shale, Upper Freeport	do.	17.6	.9238	10.2	1,628	U. S. B. M.
9.	do.	do.	18.8	.9281	12.0	1,583	1800 cc.
10.	Cannel shale, Upper Freeport	Curtisville	26.8	.9203	10.3	1,600	U. S. B. M.
10.	do.	do.	27.7	.9236	11.0	1,569	U. S. B. M.
10.	do.	do.	31.2	.9372	8.7	1,516	1800 cc.
11.	Cannel shale, Upper Freeport	Culmerville	31.4	.9094	10.5	1,539	U. S. B. M.
12.	Cannel shale, Upper Freeport	Bairdford	30.0	.9299	11.0	1,522	U. S. B. M.
13.	Carbonaceous shale, Duquesne (weathered)	Penn Township	4.6	.9588	15.2	1,770	U. S. B. M.
14.	Carbonaceous shale, Duquesne (weathered)	Franklin Township	8.7	.8866	23.7	1,620	U. S. B. M.
15.	Carbonaceous shale, Pittsburgh (weathered)	Pittsburgh	6.5	.8710	13.4	1,782	U. S. B. M.
		Armstrong County					
16.	Bituminous coal, Lower Kittanning	New Bethlehem	22.0	.9001	19.0	1,383	1800 cc.
17.	Cannel shale, Middle Kittanning	Bradys Bend Township	28.0	.9553	12.6	1,528	U. S. B. M.
17.	do.	do.	30.8	.9699	10.1	1,495	1800 cc.
18.	Bituminous coal, Upper Kittanning	New Bethlehem, 1½ mi. S.	26.1	.9688	16.5	1,352	1800 cc.
19.	Cannel coal, Upper Kittanning	do.	32.9	.9124	9.0	1,536	U. S. B. M.
19.	do.	do.	31.6	.9063	9.1	1,480	1800 cc.
20.	"Curly" cannel coal, Upper Kittanning	do.	34.6	.9201	9.4	1,454	U. S. B. M.
21.	Cannel shale, Upper Kittanning	do.	22.3	.9065	9.5	1,633	U. S. B. M.
22.	Carbonaceous shale, Upper Kittanning	do.	7.8	.9094	11.7	1,783	U. S. B. M.
23.	Cannel coal, Upper Kittanning	Gruver farm, Red Bank Township	30.7	.9268	9.9	1,481	U. S. B. M.
24.	Cannel coal, Upper Kittanning (weathered)	Ganner mine, Bradys Bend Township	34.8	.9383	11.2	1,455	U. S. B. M.
25.	Carbonaceous shale, Upper Kittanning, (weathered)	East Franklin Township	3.4	.9546	12.5	1,801	U. S. B. M.
25.	do.	do	3.9	.9682	13.3	1,782	1800 cc.
26.	Carbonaceous shale, Upper Kittanning, (weathered)	do.	6.0	.9372	14.4	1,741	U. S. B. M.
27.	Cannel shale, Upper Kittanning (weathered)	do.	18.6	.9164	15.5	1,617	U. S. B. M.
28.	Bituminous coal, Lower Freeport	New Bethlehem	23.4	.9967	14.9	1,401	1800 cc.
29.	Cannel shale, Lower Freeport (weathered)	Aladdin	35.4	.9048	9.8	1,505	U. S. B. M.
29.	do.	do.	36.3	.9086	9.1	1,485	1800 cc.

Carbonization tests on coal and carbonaceous shale (cont'd.)

No. of sample	Character of sample	Locality	Oil or tar, gallons	Specific gravity of oil or tar	Ammoniacal liquor, gallons	Weight of residue, pound	Retort used
30.	Cannel shale, Lower Freeport (weathered)	Schenley	23.9	.8924	18.3	1,480	U. S. B. M.
31.	Cannel shale, Lower Freeport (weathered)	Schenley, ½ mi. S. E.	34.5	.8870	10.0	1,506	U. S. B. M.
32.	Bituminous coal, Upper Freeport	New Bethlehem	25.8	1.0058	13.7	1,416	1800 cc.
33.	Cannel shale, Upper Freeport	do.	18.3	.9595	13.2	1,561	U. S. B. M.
		Beaver County					
34.	Bituminous coal, Lower Kittanning	Industry	24.6	.9008	11.9	1,241	1800 cc.
35.	Cannel coal, Upper Kittanning	Paragon Co., Cannelton	54.3	.9571*	8.4	1,317	U. S. B. M.
35.	do.	do.	55.5	.9669*	8.7	1,308	U. S. B. M.
35.	do.	do.	50.1	.9519*	8.2	1,332	3500 cc.
35.	do.	do.	48.5	.9452*	8.2	1,388	3500 cc.
36.	Cannel shale, Upper Kittanning	Wistar Corp., Cannelton	44.0	.9399	9.5	1,437	U. S. B. M.
37.	Bituminous coal, Upper Kittanning	Abandoned mine Cannelton	34.3	.9732	16.6	1,291	1800 cc.
38.	Cannel coal, Upper Kittanning	do.	48.2	.9279	12.2	1,299	U. S. B. M.
38.	do.	do.	46.3	.9323	12.4	1,320	U. S. B. M.
38.	do.	do.	46.9	.9325	14.2	1,292	1800 cc.
39.	Cannel coal, Upper Kittanning	do.	49.4	.9369	10.5	1,277	U. S. B. M.
40.	Cannel shale, Upper Kittanning	do.	30.7	.9342	10.7	1,514	U. S. B. M.
40.	do.	do.	32.6	.9361	11.9	1,522	U. S. B. M.
40.	do.	do.	34.5	.9372	10.2	1,496	1800 cc.
41.	Cannel shale, Upper Kittanning	Wistar Corp., Cannelton	15.0	.9320	13.0	1,658	U. S. B. M.
42.	Bony coal, Probably Upper Kittanning	Daugherty Township	26.5	.9776	11.2	1,451	U. S. B. M.
43.	Bituminous coal, Upper Freeport	Keystone Co., Cannelton	23.2	1.0014	18.6	1,385	1800 cc.
44.	Bituminous coal, Upper Freeport	Pgh. Can. Co., Cannelton	24.1	1.0151*	19.3	1,361	3500 cc.
45.	Bituminous coal, Probably Mahoning	Union C. & C. Co., Cannelton	27.5	.9997	17.4	1,337	1800 cc.
46.	Cannel shale, Probably Brush Creek	Plugh, country bank, Daugherty Township	23.8	.9566	11.9	1,456	U. S. B. M.
46.	do.	do.	24.7	.9635	12.4	1,427	1800 cc.
47.	Carbonaceous shale, Probably Brush Creek, (weathered)	do.	5.1	.9268	20.4	1,653	U. S. B. M.
48.	Cannel shale, Brush Creek	Longnecker, country bank, North Sewickley Township	22.0	.9616	15.3	1,485	U. S. B. M.
49.	Cannel coal, Bakerstown (weathered)	Greene Township	34.5	.9806	16.0	1,546	U. S. B. M.
		Blair County					
50.	Carbonaceous shale, Burket (weathered)	East Altoona,	none	----------	11.5	1,873	U. S. B. M.
		Butler County					
51.	Bituminous coal, (lower bench) Brookville	Bessemer mine, Deegan	21.8	1.0092	19.1	1,362	1800 cc.
52.	Bituminous coal, (upper bench) Brookville	do.	23.5	.9947	18.8	1,374	1800 cc.
53.	Cannel coal, Upper Kittanning	Annandale, Deegan	37.2	.9519	13.2	1,427	U. S. B. M.
54.	Cannel shale, Upper Kittanning	do.	28.9	.9504	13.4	1,492	U. S. B. M.
55.	Cannel coal, Upper Kittanning	Washington Township	34.4	.9572	13.2	1,418	U. S. B. M.
55.	do.	do.	32.7	.9447	14.0	1,400	1800 cc.
56.	Carbonaceous shale, Upper Kittanning	do.	11.8	.9553	12.3	1,585	U. S. B. M.
57.	Cannel shale, Upper Kittanning (weathered)	Parker Township	27.3	.9278	13.6	1,574	U. S. B. M.
58.	Cannel coal, Probably Upper Kittanning	McCandless prospect, Franklin Township	11.4	.9413	10.9	1,348	U. S. B. M.
58.	do.	do.	40.3	.9438	11.1	1,327	1800 cc.
59.	Cannel shale, Probably Upper Kittanning	do.	33.2	.9583	11.8	1,403	U. S. B. M.
59.	do.	do.	30.9	.9478	10.7	1,413	1800 cc.
60.	Cannel shale, Probably Upper Kittanning	McBride, Franklin Township	20.0	.9515	13.7	1,538	U. S. B. M.
61.	Cannel shale, Probably Upper Kittanning	Franklin Township	20.7	.9524	17.1	1,528	U. S. B. M.
62.	Cannel coal, Probably Upper Kittanning	Currie, country bank, Worth Township	33.0	.9651	14.5	1,398	U. S. B. M.
62.	do.	do.	33.4	.9683	13.7	1,376	1800 cc.
63.	Carbonaceous shale, Probably Upper Kittanning	do.	14.8	.9648	14.5	1,601	U. S. B. M.
64.	Cannel shale, Probably Upper Kittanning (weathered)	Clay Township	36.3	.9420	12.4	1,407	U. S. B. M.
65.	Cannel shale, Upper Freeport	Marburger, country bank, Forward Township	32.6	.9648	11.3	1,435	U. S. B. M.
		Center County					
66.	Semi-bituminous coal, Lower Kittanning	Moshannon No. 11 mine Philipsburg,	10.0	1.0053	8.9	1,572	1800 cc.
67.	Canneloid semi-bituminous coal, Lower Kittanning	do.	9.0	.9093	9.7	1,669	U. S. B. M.
67.	do.	do.	9.3	.9495	9.4	1,634	1800 cc.

Carbonization tests on coal and carbonaceous shale (cont'd.)

No. of sample	Character of sample	Locality	Oil or tar, gallons	Specific gravity of oil or tar	Ammoniacal liquor, gallons	Weight of residue, pounds	Retort used
		Clearfield County					
68.	Canneloid semi-bituminous coal. Probably Lower Kittanning	Carnel Crest mine, Woodland	10.3	.9310	7.5	1,682	U. S. B. M.
68.	do.	do.	10.9	.9418	7.7	1,643	1800 cc.
69.	Canneloid semi-bituminous coal Probably Middle Kittanning (weathered)	Overly farm, Woodland	11.1	.9744	9.5	1,637	U. S. B. M.
70.	Semi-bituminous coal. Probably Upper Kittanning	Sterling No. 2 mine, Woodward Township	10.4	.9866	8.3	1,585	1800 cc.
71.	Canneloid semi-bituminous coal Probably Upper Kittanning	do.	9.3	.9941	6.4	1,676	U. S. B. M.
71.	do.	do.	9.4	.9943	8.0	1,661	1800 cc.
72.	Canneloid semi-bituminous shale. Probably Upper Kittanning	do.	4.5	.9516	10.2	1,797	U. S. B. M.
73.	Carbonaceous shale. Probably Upper Kittanning	do.	1.5	.9211	10.7	1,843	U. S. B. M.
74.	Semi-bituminous coal. Lower Freeport	Hartley mine, Graham Station	6.8	1.0330	11.0	1,609	1800 cc.
		Fayette County					
75.	Cannel shale, Redstone (weathered)	Nicholson Township	10.6	.8607	21.8	1,518	U. S. B. M.
		Greene County					
76.	Cannel shale, Redstone	Gabler prospect, Monongahela Township	26.5	.8820	12.3	1,515	U. S. B. M.
76.	do.	do.	26.7	.8808	12.4	1,532	U. S. B. M.
76.	do.	do.	27.1	.8854	12.6	1,509	1800 cc.
77.	Bituminous coal, Sewickley	Black country bank Monongahela Township	23.8	1.0139	12.6	1,409	1800 cc.
78.	Carbonaceous shale, Uniontown (weathered)	Monongahela Township	7.4	.8726	12.8	1,787	U. S. B. M.
79.	Bituminous coal, Waynesburg	Moredock mine, Franklin Township	26.2	1.0411	13.6	1,427	1800 cc.
80.	Carbonaceous shale, below Washington coal (weathered)	Purman Run, Waynesburg	11.1	.8735	17.6	1,718	U. S. B. M.
81.	Carbonaceous shale, above Washington coal (weathered)	do.	2.9	.8989	21.4	1,703	U. S. B. M.
82.	Cannel shale. above Upper Washington limestone	Boyd Run, Washington Township	11.2	.9140	10.2	1,642	U. S. B. M.
		Indiana County					
83.	Cannel coal, Upper Kittanning	Bicknell Bros. mine, Grant Township	19.0	.9490	11.4	1,545	1800 cc.
84.	Cannel shale, Upper Kittanning	do.	5.3	.9497	11.7	1,686	U. S. B. M.
85.	Bone, Upper Freeport	Ernest, Rayne Township	10.5	.9868	14.3	1,673	U. S. B. M.
86.	Carbonaceous shale. Possibly Bakerstown (weathered)	South Mahoning Township	6.3	.9418	12.2	1,623	U. S. B. M.
		Jefferson County					
87.	Cannel shale, Lower Freeport	Coal Glen	29.6	.9481	7.0	1,534	U. S. B. M.
		Lawrence County					
88.	Cannel shale, Probably Upper Kittanning	Stewart farm, Little Beaver Township	37.4	.9420	11.5	1,429	U. S. B. M.
		Luzerne County					
89.	Anthracite, Hillman bed	Stanton No. 7, Wilkes-Barre	none		9.0	1,901	U. S. B. M.
89.	do.	do.	none		7.2	1,897	1800 cc.
90.	Canneloid anthracite, Hillman bed	do.	none		7.0	1,915	U. S. B. M.
		Lycoming County					
91.	Semi-bituminous coal, "B" bed	Ralston	1	1.0622	8.4	1,733	1800 cc.
		Mercer County					
92.	Cannel shale. Probably Sharon	Springfield Township	48	.8810	11.5	1,374	U. S. B. M.
92.	do.	do.	49	.8742	12.1	1,336	1800 cc.
93.	Bituminous coal, Brookville	Diamond No. 3 mine, Pine Township	24	1.0208*	19.4	1,335	3500 cc.
93.	do.	do.	24	1.0124*	18.2	1,471	3500 cc.
		Sullivan County					
94.	Semi-anthracite, Bernice or "B" bed	Murray mine, Lopez	trace		7.2	1,815	1800 cc.

Carbonization tests on coal and carbonaceous shale (cont'd.)

No. of sample	Character of sample	Locality	Oil or tar, gallons	Specific gravity of oil or tar	Ammoniacal liquor, gallons	Weight of residue, pounds	Retort used
		Tioga County					
95.	Semi-bituminous coal, Bloss bed	Bower mine, Blossburg	6.2	1.0253	7.2	1,666	1800 cc.
96.	Carbonaceous shale, Cannel bed	Morris Run	2.5	.9187	12.3	1,797	U. S. B. M.
97.	Canneloid semi-bituminous shale Cannel bed	do.	2.6	.8933	12.3	1,774	U. S. B. M.
		Washington County					
98.	Bituminous coal, Pittsburgh	Arden No. 2 mine, Chartiers Township	29.0	1.0258*	19.3	1,341	3500 cc.
98.	do.	do.	30.1	1.0399*	16.9	1,378	3500 cc.
99.	Bituminous coal, Pittsburgh	Ellsworth	23.3	1.0101	14.4	1,429	1800 cc.
100.	Coal washer refuse from Pittsburgh coal	do.	3.5	1.0050	20.0	1,695	U. S. B. M.
101.	Bituminous coal, Pittsburgh	Langeloth	19.3	1.0139	18.3	1,372	1800 cc.
		Westmoreland County					
102.	Cannel shale, Lower Freeport	Kiskiminitas Junction	37.1	.8885*	14.0	1,475	U. S. B. M.
102.	do.	do.	38.2	.8901*	13.1	1,466	U. S. B. M.
102.	do.	do.	37.5	.8811*	11.7	1,460	3500 cc.
102.	do.	do.	36.6	.8790*	10.3	1,499	3500 cc.
103.	Cannel shale, Lower Freeport	do.	39.4	.8941	10.0	1,466	U. S. B. M.
103.	do.	do.	37.6	.8894	10.6	1,470	U. S. B. M.
103.	do.	do.	33.3	.8890	10.1	1,453	1800 cc.
104.	Cannel shale, Lower Freeport	Lucesco mine, Kiskiminitas Junction	36.3	.8873	13.1	1,493	U. S. B. M.
105.	Bituminous coal, Upper Freeport	Parnassus	23.8	1.0144*	15.3	1,372	3500 cc.
105.	do.	do.	23.4	1.0000*	13.3	1,510	3500 cc.
106.	Bone, Upper Freeport	do.	16.3	1.0167*	17.5	1,544	U. S. B. M.
106.	do.	do.	16.8	1.0127*	17.5	1,580	U. S. B. M.
106.	do.	do.	14.8	1.0138*	17.3	1,565	3500 cc.
106.	do.	do.	14.9	1.0076*	16.4	1,539	3500 cc.
106.	do.	do.	13.8	1.0037*	15.3	1,538	3500 cc.
106.	do.	do.	15.6	1.0074*	15.9	1,586	3500 cc.
107.	Cannel shale, Upper Freeport	do.	39.2	.9044*	10.2	1,430	U. S. B. M.
107.	do.	do.	39.1	.9050*	11.4	1,431	U. S. B. M.
107.	do.	do.	38.2	.8975*	10.0	1,446	3500 cc.
107.	do.	do.	38.2	.9058*	10.2	1,446	3500 cc.
108.	Cannel shale, Upper Freeport	Darlington	11.3	.9656	7.8	1,641	U. S. B. M.
		Samples from other States					
109.	Oil shale, Chattanooga	Means, Montgomery Co., Ky.	8.6	.9337	13.4	1,724	U. S. B. M.
110.	Oil shale, Chattanooga	Clay City, Powell Co., Ky.	17.7	.9224*	7.6	1.616	U. S. B. M.
110.	do.	do.	17.8	.9316*	7.9	1,551	U. S. B. M.
110.	do.	do.	16.6	.9189*	7.9	1,465	3500 cc.
110.	do.	do.	17.1	.9274*	6.1	1,705	3500 cc.
111.	Oil shale, Chattanooga	Redboiling Springs, Macon Co., Tenn.	9.8	.9079	7.2	1,781	U. S. B. M.
112.	Oil shale,	Nova Scotia	47.8	.8698	6.3	1,424	U. S. B. M.
113.	Oil shale, Green River Eocene	Grand Valley, Garfield Co., Colorado.	44.7	.8905	4.4	1,451	U. S. B. M.
113.	do.	do.	34.5	.8811	5.6	1,374	1800 cc.
113.	do.	do.	35.1	.9137	4.9	1,259	1800 cc.
114.	do.	do.	16.5	.8951	3.4	1,641	U. S. B. M.
115.	do.	12 mi. N. of DeBeque, Garfield Co., Col.	45.1	.9110*	5.6	1,326	U. S. B. M.
115.	do.	do.	44.9	.9030*	5.6	1,341	U. S. B. M.
115.	do.	do.	44.7	.8937*	5.4	1,224	3500 cc.
115.	do.	do.	41.6	.8864*	4.8	1,483	3500 cc.
115.	do.	do.	41.9	.8841*	4.8	1,427	3500 cc.
116.	do.	Kimball Creek, DeBeque, Colo.	47.0	.8960	4.8	1,454	U. S. B. M.
117.	do.	Grand Valley, Garfield Co., Colo.	65.9	.8816	6.7	1,205	U. S. B. M.
118.	do.	Watson, Uinta County, Utah	66.2	.8703	9.2	1,219	U. S. B. M.
119.	Lignite, Fort Union, (Eocene)	Kenmare, Ward County, N. Dak.	4.8	1.0246	54.3	1,116	1800 cc.
120.	Lignite (Tertiary)	Mississippi	9.2	.9470	15.3	1,645	U. S. B. M.
121.	Oil shale, (Miocene)	Elko, Nevada	52.6	.8602	12.7	1,341	U. S. B. M.
121.	do.	do.	50.7	.8620	12.7	1,335	U. S. B. M.
121.	do.	do.	47.5	.8581	13.0	1,330	1800 cc.
122.	do.	do.	24.5	.9099*	19.3	1,500	U. S. B. M.
122.	do.	do.	23.8	.9034*	22.4	1,478	U. S. B. M.
122.	do.	do.	24.5	.8893*	19.2	1,490	3500 cc.

*Specific gravities determined at a temperature of 60° F. (15.56° C.). All other specific gravities determined with oil at 25° C. and compared with water at 15.56° C.

The results of those carbonization tests made in the 1800 c. c. retort are included in the table that follows. The temperature was carried to 1400° F. on the indicator. The yield of oil tar, light oil when determined, and ammonical liquor are given, computed on the basis of gallons per ton of 2,000 pounds. Also are included the yield of ammonia as such and computed on the basis of pure ammonium sulphate in pounds per ton, the weight of the residue in pounds per ton, the specific gravities of the oil or tar and light oil (determined at 25° C. and compared with water at 15.56° C.), the percentage of the total nitrogen of the original sample recovered as ammonia, and a description of the physical character of the residue.

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Results of carbonization tests in 1800 c. c. retort.

No. of sample	Character of sample	Oil or tar, gallons	Sp. gr. of oil or tar	Light oil, gallons	Sp. gr. of light oil	Ammoniacal liquor, gallons	Ammonia, pounds	Ammonium sulphate pounds	Per cent N recovered as ammonia	Residue, pounds	Description of residue
					Allegheny County						
2.	Bituminous coal Upper Freeport	24.8	.9796	----------	----------	16.9	6.34	24.59	16	1,368	Hard, rather dense coke.
3.	Cannel shale U. Free.	30.4	.9226	----------	----------	12.5	4.08	15.83	17	1,479	Practically no tendency to cake.
4.	Cannel shale U. Free.	15.7	.9318	----------	----------	10.7	2.17	8.42	20	1,653	No tendency to cake
7.	Bone Upper Freeport	18.1	.9828	----------	----------	15.2	4.81	18.66	20	1,574	Slight tendency to cake
8.	Cannel shale U. Free.	36.7	.9006	----------	----------	12.2	5.43	21.06	17	1,427	Practically no tendency to cake.
9.	Cannel shale U. Free.	18.8	.9281	----------	----------	12.0	2.45	9.50	17	1,583	No tendency to cake
10.	Cannel shale U. Free.	31.2	.9372	----------	----------	8.7	3.68	14.27	15	1,516	Practically no tendency to cake.
					Armstrong County						
16.	Bituminous coal L. Kittanning.	22.0	.9901	----------	----------	19.0	4.57	17.73	15	1,383	Hard porous coke
17.	Cannel shale, M. Kitt.	30.8	.9699	----------	----------	10.1	4.14	16.06	17	1,495	Practically no tendency to cake.
18.	Bituminous coal, U. Kitt.	26.1	.9688	----------	----------	16.5	5.51	21.37	13	1,352	Hard porous coke
19.	Cannel coal, U. Kitt.	31.6	.9063	----------	----------	9.1	5.40	20.95	18	1,480	Very little tendency to cake.
25.	Carbonaceous shale (weathered) U. Kitt.	3.9	.9682	----------	----------	13.3	1.77	6.87	29	1,782	No tendency to cake
28.	Bituminous coal, L. Free.	23.4	.9967	----------	----------	14.9	6.10	23.66	18	1,401	Hard porous coke
29.	Cannel shale, (weathered) L. Free.	36.3	.9086	----------	----------	9.1	3.40	13.19	15	1,485	No tendency to cake
32.	Bituminous coal, U. Free.	25.8	1.0058	----------	----------	13.7	5.30	20.56	14	1,416	Hard, rather dense coke.
					Beaver County						
34.	Bituminous coal, L. Kitt.	24.6	.9908	----------	----------	11.9	4.25	16.49	13	1,241	Brittle, porous coke
37.	Bituminous coal, U. Kitt.	34.3	.9732	----------	----------	16.6	6.50	25.21	14	1,291	Hard, moderately porous coke.
38.	Cannel coal, U. Kitt.	46.9	.9325	----------	----------	14.2	4.22	16.37	13	1,292	Hard dense coke
40.	Cannel shale, U. Kitt.	34.5	.9372	----------	----------	10.2	3.01	11.68	16	1,496	No tendency to cake
43.	Bituminous coal, U. Free.	23.2	1.0014	----------	----------	18.6	6.29	24.40	16	1,385	Hard dense coke
45.	Bituminous coal, Mahoning.	27.5	.9997	----------	----------	17.4	6.21	24.09	16	1,337	Hard porous coke
46.	Cannel shale, Brush Creek.	24.7	.9635	----------	----------	12.4	5.15	19.94	20	1,427	Very little tendency to cake.
					Butler County						
51.	Bituminous coal, lower bench, Brookville.	21.8	1.0092	----------	----------	19.1	4.36	16.91	15	1,362	Hard porous coke
52.	Bituminous coal, upper bench, Brookville.	23.5	.9947	----------	----------	18.8	5.24	20.33	17	1,374	Hard porous coke
55.	Cannel coal, U. Kitt.	32.7	.9447	----------	----------	14.0	5.15	19.98	16	1,400	Slight tendency to cake
58.	Cannel coal, U. Kitt.	40.3	.9438	----------	----------	11.1	4.57	17.73	13	1,327	Slight tendency to cake
59.	Cannel shale, U. Kitt.	30.9	.9478	----------	----------	10.7	4.19	16.25	14	1,413	Very slight tendency to cake.
62.	Cannel coal, U. Kitt.	33.4	.9683	1.8	.7232	13.7	5.89	22.85	16	1,376	Hard dense coke

Results of carbonization tests in 1800 c. c. retort (cont'd.)

No. of sample	Character of sample	Oil or tar, gallons	Sp. gr. of oil or tar	Light oil, gallons	Sp. gr. of light oil	Ammoniacal liquor, gallons	Ammonia, pounds	Ammonium sulphate pounds	Per cent N recovered as ammonia	Residue, pounds	Description of residue
					Center County						
66.	Semi-bituminous coal, L. Kitt.	10.0	1.0053	----------	----------	8.9	4.15	16.10	12	1,572	Hard dense coke
67.	Canneloid semi-bit. coal, L. Kitt.	9.3	.9495	----------	----------	9.4	4.48	17.38	14	1,634	Practically no tendency to cake.
					Clearfield County						
68.	Canneloid semi-bit. coal, L. Kitt.	10.9	.9418	----------	----------	7.7	5.46	21.17	16	1,643	Slight tendency to cake
70.	Semi-bituminous coal, U. Kitt.	10.4	.9866	----------	----------	8.3	4.47	17.34	11	1,585	Hard dense coke
71.	Canneloid semi-bit. coal, U. Kitt.	9.4	.9943	----------	----------	8.0	4.41	17.11	13	1,661	Very slight tendency to cake.
74.	Semi-bit. coal, L. Free.	6.8	1.0330	----------	----------	11.0	5.38	20.87	14	1,669	No tendency to cake
					Greene County						
76.	Cannel shale, Redstone	27.1	.8854	1.8	.7103	12.6	3.36	13.03	15	1,509	Practically no tendency to cake.
77.	Bituminous coal, Sewickley	23.8	1.0139	1.9	.7587	12.6	5.50	21.33	15	1,409	Hard porous coke
79.	Bituminous coal, Waynesburg	26.2	1.0411	1.8	.7613	13.6	6.71	25.03	20	1,427	Hard porons coke
					Indiana County						
83.	Cannel coal, U. Kitt.	19.0	.9490	1.7	.7267	11.4	5.61	21.76	17	1,545	Hard porous coke
					Luzerne County						
89.	Anthracite, Hillman bed	none	----------	none	----------	7.2	4.07	15.75	17	1,897	Very little change in appearance.
					Lycoming County						
91.	Semi-bituminous coal, "B" bed	1.9	1.0622	.9	.8144	8.4	4.77	18.50	18	1,733	Practically no tendency to cake.
					Mercer County						
92.	Cannel shale, Sharon,	49.2	.8742	2.1	.7092	12.1	2.22	8.61	17	1,336	No tendency to cake
					Sullivan County						
94.	Semi-anthracite, Bernice or "B" bed	trace	----------	.1	----------	7.2	5.08	19.71	19	1,815	No tendency to cake
					Tioga County						
95.	Semi-bituminous coal, Bloss bed	6.2	1.0253	1.4	.7812	7.2	4.85	18.81	17	1,666	Hard dense coke
					Washington County						
99.	Bituminous coal, Pittsburgh.	23.3	1.0101	1.9	.7480	14.4	5.86	22.73	15	1,429	Hard porous coke
101.	Bituminous coal, Pittsburgh	19.3*	1.0139	1.9	.7742	18.3	6.11	23.70	17	1,372	Hard dense coke
					Westmoreland County						
103.	Cannel shale, L. Free.	33.3	.8890	2.5	.7135	10.1	2.96	11.48	13	1,453	Practically no tendency to cake.
					Samples from other States						
113.	Oil shale. Green River Eocene. Colo.	34.5*	.8811	2.2	.7125	5.6	3.63	14.08	16	1,374	Very little tendency to cake.
113.	do.	35.1*	.9137	1.9	.7076	4.9	4.54	17.57	20	1,259	Very little tendency to cake.
119.	Lignite, Fort Union Eocene, N. Dak.	4.8	1.0246	.8	.8414	54.3	3.36	13.03	23	1,116	No tendency to cake
121.	Oil shale, Miocene, Nev.	47.5	.8581	1.7	.7360	13.0	2.21	8.57	16	1,330	No tendency to cake

*Results low due to development of slight leak in retort.

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Analyses of coal and shale tested in 1800 c. c. retort.

No. of sample	Character of sample	Moisture	Volatile matter	Fixed carbon	Ash	Total nitrogen
	Allegheny County					
2.	Bituminous coal, Upper Freeport	.78	36.17	56.38	6.67	1.62
3.	Cannel shale, Upper Freeport	.35	29.98	36.15	33.52	1.00
4.	Cannel shale, Upper Freeport	.38	18.21	19.74	61.67	.43
7.	Bone, Upper Freeport	.96	25.17	30.33	43.54	.99
8.	Cannel shale, Upper Freeport	.32	34.48	38.20	27.00	1.29
9.	Cannel shale, Upper Freeport	.46	24.34	20.79	54.41	.60
10.	Cannel shale, Upper Freeport	.39	27.54	32.40	39.67	1.03
	Armstrong County					
16.	Bituminous coal, Lower Kittanning	.85	36.62	49.61	12.92	1.26
17.	Cannel shale, Middle Kittanning	.17	30.61	35.33	33.89	1.03
18.	Bituminous coal, Upper Kittanning	.58	36.82	55.80	6.79	1.81
19.	Cannel coal, Upper Kittanning	.37	31.29	43.48	24.86	1.21
25.	Carbonaceous shale, (weathered), Upper Kittanning	.83	12.65	6.67	79.85	.27
28.	Bituminous coal, Lower Freeport	1.14	33.87	55.65	9.34	1.37
29.	Cannel shale, (weathered), Lower Freeport	.56	30.52	32.06	36.86	.92
32.	Bituminous coal, Upper Freeport	1.18	33.52	57.63	7.67	1.52
	Beaver County					
34.	Bituminous coal, Lower Kittanning	.35	42.15	48.47	9.03	1.31
37.	Bituminous coal, Upper Kittanning	1.34	42.41	52.05	4.20	1.87
38.	Cannel coal, Upper Kittanning	1.26	44.49	34.28	19.97	1.29
40.	Cannel shale, Upper Kittanning	.56	28.15	23.57	47.72	.77
43.	Bituminous coal, Upper Freeport	1.14	35.80	53.44	9.62	1.66
45.	Bituminous coal, Probably Mahoning	1.13	38.57	53.38	6.92	1.60
46.	Cannel shale, Probably Brush Creek	.69	35.50	33.95	29.86	1.08
	Butler County					
51.	Bituminous coal, (lower bench), Brookville	1.00	37.46	48.36	13.18	1.21
52.	Bituminous coal, (upper bench), Brookville	.83	39.19	46.64	13.34	1.29
55.	Cannel coal, Upper Kittanning	.90	37.46	37.42	24.22	1.36
58.	Cannel coal, Probably Upper Kittanning	.84	42.21	35.15	21.80	1.42
59.	Cannel shale, Probably Upper Kittanning	.91	37.66	31.36	30.07	1.25
62.	Cannel coal, Probably Upper Kittanning	.83	38.94	49.14	11.09	1.49
	Center County					
66.	Semi-bituminous coal, Lower Kittanning	.52	23.18	66.38	9.92	1.42
67.	Canneloid, semi-bituminous coal, Lower Kittanning	.50	19.48	57.53	22.49	1.36
	Clearfield County					
68.	Canneloid, semi-bituminous coal, Probably Lower Kittanning	.30	20.42	55.51	23.77	1.37
70.	Semi-bituminous coal, Probably Upper Kittanning	.53	23.71	63.98	11.78	1.62
71.	Canneloid, semi-bituminous coal, Probably Upper Kittanning	.54	21.32	65.41	12.73	1.39
74.	Semi-bituminous coal, Lower Freeport	1.41	24.29	68.77	5.53	1.63
	Greene County					
76.	Cannel shale, Redstone	.64	28.49	24.77	46.10	.91
77.	Bituminous coal, Sewickley	.81	34.15	54.54	10.50	1.53
79.	Bituminous coal, Waynesburg	1.30	34.70	47.68	16.32	1.40
	Indiana County					
83.	Cannel coal, Upper Kittanning	.53	27.64	53.98	17.85	1.38
	Luzerne County					
89.	Anthracite, Hillman bed	.24	9.18	73.45	17.13	.98

Analyses of coal and shale tested in 1800 c. c. retort (cont'd.)

No. of sample	Character of sample	Moisture	Volatile matter	Fixed carbon	Ash	Total nitrogen
	Lycoming County					
91.	Semi-bituminous coal, "B" bed	.44	17.19	64.29	18.08	1.07
	Mercer County					
92.	Cannel shale, Probably Sharon	.52	35.47	20.73	43.28	.54
	Sullivan County					
94.	Semi-anthracite, Bernice or "B" bed	.43	10.78	76.67	12.12	1.09
	Tioga County					
95.	Semi-bituminous coal, Bloss bed	.22	18.96	67.94	12.88	1.18
	Washington County					
99.	Bituminous coal, Pittsburgh	.98	34.67	57.79	6.56	1.56
101.	Bituminous coal, Pittsburgh	3.21	36.18	51.63	8.98	1.39
	Westmoreland County					
103.	Cannel shale, Lower Freeport	.76	30.46	31.78	37.00	.92
	Samples from other States					
113.	Oil shale, Green River, Eocene	.58	39.52	3.41	56.49	.91
119.	Lignite, Fort Union, Eocene	11.16	37.70	45.93	5.21	.61
121.	Oil shale, Miocene	1.93	37.70	7.07	53.30	.58

Results of carbonization tests in 3500 c. c. retort.

No. of sample	Character of sample	Test No.	Maximum temperature reached on recorder (° F.)	Weight of sample (grams)	Oil or tar (c. c.)	Light oil (c. c.)	Ammoniacal liquor (c. c.)	Ammonia in ammoniacal liquor (grams)	Pyridine in ammoniacal liquor (grams)	Sulphur in ammoniacal liquor (grams)	Ammonia in sulphuric acid wash water (grams)	Pyridine in sulphuric acid wash water (grams)	Weight of residue (grams)	Volume of gas at 60° F., 30 in. Hg sat. with moisture (cu. ft.)
35.	Cannel coal, U. Kitt.	1	1,400	2,609.2	545.0	30.9	90.0	1.50056	.03236	.43182	2.72904	.03236	1,738.0	18.013
35.	do.	2	900	2.646.7	535.0	35.2	90.0	1.56324	.06472	.90009	1.23176	.04854	1,837.3	11.198
44.	Bituminous coal. U. Free.	1	1,400	2,739.0	275.0	25.0	220.0	2.50568	.03236	.63842	5.49640	.08090	1.864.5	26.407
93.	Bituminous coal, Brookville.	1	1,400	2,718.6	280.0	25.80	220.0	2.77232	.03236	1.30142	5.34007	.05987	1,815.0	26.888
93.	do.	2	900	2,890.0	295.0	20.2	220.0	1.73722	.02265	.68170	.35982	.06957	2,125.0	11.846
98.	Bituminous coal. Pittsburgh.	1	1,400	2,736.5	330.0	25.5	220.0	2.59656	trace	1.55221	6.96248	.01618	1.828.5	24.204
98.	do.	2	900	2,629.0	330.0	25.4	185.0	2.37292	.06472	1.02284	2.79528	.04854	1.811.0	15.782
102.	Cannel shale, L. Free.	1	1,400	2,974.0	465.0	30.3	145.0	1.82654	.01618	.12385	1.24530	.08090	2,171.0	15,081
102.	do.	2	900	3,013.5	460.0	31.7	130.0	1.46224	.01618	.04055	.93176	.01618	2,259.0	11.074
105.	Bituminous coal, U. Free.	1	1,400	2,667.5	265.0	31.8	170.0	1.58729	.04872	.26578	5.82371	.06496	1,829.5	28.88
105.	do.	2	900	2.712.0	265.0	23.6	150.0	2.26128	.04872	.39100	.75571	.06496	2,048.0	9.624
106.	Bone, U. Free.	1	1,400	3,178.2	196.0	--------	230.0	--------	--------	--------	--------	--------	2,487.5	20.129
106.	do.	2	1,400	3,210.2	200.0	20.7	220.0	2.97614	.08120	.56910	6.80014	.08120	2,471.0	20.084
106.	do.	3	1,400	3,136.0	180.0	19.1	200.0	--------	--------	--------	--------	--------	2,411.0	17.960
106.	do.	4	1,400	3,158.0	205.0	25.1	210.0	3.44371	.06496	.77761	5.77456	.09744	2,505.0	17.802
107.	Cannel shale, U. Free.	1	1,400	2,759.5	440.0	22.2	115.0	2.06456	.09744	1.08257	2.47414	.08120	1.995.3	18.487
107.	do.	2	1,400	2,826.0	450.0	30.4	120.0	2.53682	.01287	.99462	4.54570	trace	2,043.8	20.247
110.	Oil shale, Chattanooga	1	1,400	3.959.0	275.0	25.6	130.0	4.18748	.04045	.6231	2.09407	.03236	2,899.5	26,922
110.	do.	2	900	4,123.5	295.0	26.6	105.0	2.68300	trace	.70144	.65652	trace	3,515.5	10.621

Results of carbonization tests in 3500 c. c. retort (cont'd.)

No. of sample	Character of sample	Test No.	Maximum temperature reached on recorder (° F.)	Weight of sample (grams)	Oil or tar (c. c.)	Light oil (c. c.)	Ammoniacal liquor (c. c.)	Ammonia in ammoniacal liquor (grams)	Pyridine in ammoniacal liquor (gram)	Sulphur in ammoniacal liquor (grams)	Ammonia in sulphuric acid wash water (grams)	Pyridine in sulphuric acid wash water (grams)	Weight of residue (grams)	Volume of gas at 60° F., 30 in. Hg sat. with moisture (cu. ft.)
115.	Oil shale, Green River Eocene.	1	1,400	3,568.5	665.0	26.9	80.0	1.53888	.04824	.18495	1.74116	.08090	2,148.8	25.760
115.	do.	2	900	3,512.0	610.0	31.8	70.0	------	------	------	------	------	2,605.0	10.864
115.	do.	3	900	3,743.5	655.0	19.6	75.0	1.63660	.04854	.18221	1.20384	.04854	2,670.7	9.849
122.	Oil shale, Miocene.	1	1,400	2,929.5	300.0	27.6	235.0	2.34000	trace	.97215	1.12931	.04023	2,182.0	17.419

Yield per ton of 2,000 pounds.

No. of sample	Character of sample	Test No.	Maximum temperature reached on recorder °F.	Volume of oil or tar Gallons	Water in oil or tar Per cent	Sp. Gr. dehydrated oil at 15.56° C.	Nitrogen content of oil or tar Per cent	Sulphur content of oil or tar Per cent	Volume of light oil Gallons	Sp. Gr. light oil at 15.56° C.	Volume of ammoniacal liquor Gallons	Ammonia Pounds	Ammonium sulphate Pounds	Total nitrogen recovered as ammonia Per cent	Residue Pounds	Volume of gas, cu. ft. at 60° F., 30 in. Hg. sat. with water.
35.	Cannel coal, Upper Kittanning,	1	1400	50.1	.1	0.9519	.71	.38	2.8	0.7161	8.2	3.24	12.57	13	1332	6,266
35.	do.	2	900	48.5	.2	0.9452	.73	.32	3.2	0.6982	8.2	2.11	8.18	9	1388	3,839
44.	Bituminous coal, Upper Freeport,	1	1400	24.1	1.1	1.0151	.78	.56	2.2	0.7484	19.3	5.85	22.69	15	1361	8,749
93.	Bituminous coal, Brookville,	1	1400	24.7	1.5	1.0208	.77	.50	2.3	0.7332	19.4	5.97	23.16	18	1335	8,949
93.	do.	2	900	24.5	.7	1.0124	.68	.52	1.7	0.7065	18.2	1.45	5.62	4	1471	3,719
98.	Bituminous coal, Pittsburgh,	1	1400	29.0	1.6	1.0258	.83	.76	2.2	0.7249	19.3	7.01	27.19	23	1341	8,057
98.	do.	2	900	30.1	3.1	1.0399	.81	.99	2.3	0.7278	16.9	3.93	15.24	13	1378	5,448
102.	Cannel shale, Lower Freeport,	1	1400	37.5	none	0.8811	.45	.32	2.4	0.6979	11.7	2.07	8.03	11	1460	4,602
102.	do.	2	900	36.6	none	0.8790	.48	.33	2.5	0.6887	10.3	1.59	6.17	9	1499	3,334
105.	Bituminous coal, Upper Freeport,	1	1400	23.8	3.4	1.0144	.76	.51	2.9	0.7425	15.3	5.56	21.57	14	1372	9,828
105.	do.	2	900	23.4	1.5	0.9999	.68	.43	2.1	0.7139	13.3	2.22	8.61	6	1510	3,224
106.	Bone, Upper Freeport,	1	1400	14.8	4.1	1.0138	------	------	------	------	17.3	------	------	---	1565	5,747
106.	do.	2	1400	14.9	1.2	1.0076	.79	.32	1.5	0.7346	16.4	6.09	23.62	23	1539	5,677
106.	do.	3	1400	13.8	2.1	1.0037	------	------	1.5	0.7363	15.3	------	------	---	1538	5,197
106.	do.	4	1400	15.6	1.5	1.0074	.79	.47	1.8	0.7264	15.9	5.84	22.65	22	1586	5,116
107.	Cannel shale, Upper Freeport,	1	1400	38.2	none	0.8975	.62	.55	1.9	0.7055	10.0	3.29	12.76	11	1446	6,078
107.	do.	2	1400	38.2	none	0.9058	.54	.26	2.6	0.7024	10.2	5.01	19.43	17	1446	6,501
110.	Oil shale, Chattanooga,	1	1400	16.6	none	0.9189	1.17	1.62	1.5	0.7019	7.9	3.15	12.22	17	1465	6,171
110.	do.	2	900	17.1	none	0.9274	1.22	1.41	1.5	0.6922	6.1	1.62	6.28	9	1705	2,339
115.	Oil shale, Green River, Eocene,	1	1400	44.7	none	0.8937	1.82	.53	1.8	0.7033	5.4	1.84	7.14	11	1224	6,555
115.	do.	2	900	41.6	none	0.8864	------	------	2.2	0.6910	4.8	------	------	---	1483	2,807
115.	do.	3	900	41.9	none	0.8841	1.89	.67	1.3	0.6942	4.8	1.52	5.90	9	1427	2,388
122.	Oil shale, Miocene,	1	1400	24.5	1.4	0.8893	.65	.99	2.3	0.7178	19.2	2.37	9.19	20	1490	5,395

Proximate and ultimate analyses of the samples, tested in the 3500 c. c. retort were made for the writer by the U. S. Bureau of Mines at its Pittsburgh station. The results, computed on an air dried basis, were as follows:—

No. of sample	Character of sample	Proximate analysis			Ultimate analysis						
		Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Ash
35.	Cannel coal, Upper Kittanning	.73	39.22	32.57	27.48	4.97	60.00	1.01	4.29	2.25	27.48
44.	Bituminous coal, Upper Freeport	1.80	36.53	54.87	6.80	5.40	76.41	1.58	8.18	1.63	6.80
93.	Bituminous coal, Brookville	2.00	38.08	49.97	9.95	5.22	71.97	1.34	6.97	4.55	9.95
98.	Bituminous coal, Pittsburgh	1.43	39.07	51.60	7.90	5.41	74.46	1.28	8.33	2.62	7.90
102.	Cannel shale, Lower Freeport	.73	26.62	26.45	46.20	3.70	43.27	.76	4.49	1.58	46.20
105.	Bituminous coal, Upper Freeport	1.10	35.55	55.20	8.15	5.27	76.82	1.62	6.66	1.48	8.15
106.	Bone, Upper Freeport	1.00	24.55	36.65	37.80	3.65	50.26	1.08	5.99	1.22	37.80
107.	Cannel shale, Upper Freeport	.18	32.12	36.17	31.53	4.58	57.35	1.19	3.12	2.23	31.53
110.	Oil shale, Chattanooga	.73	27.65	4.74	66.88	2.09	21.33	.74	6.88	2.08	66.88
115.	Oil shale, Green River Eocene	.55	39.78	.37	50.30	2.86	26.07	.69	9.91	1.17	59.30
122.	Oil shale, Miocene	2.78	22.30	9.77	65.15	2.98	21.19	.49	5.26	4.93	65.15

Proximate analyses were made of the spent material or residue from the carbonization tests in the 3500 c. c. retort. The nitrogen and sulphur content were also determined. These results are given in the table which follows. The analyses indicate that appreciable quantities of water were absorbed by the material while remaining in the laboratory for several months. In the case of the residues of some of the shales carbonized to only 900° F. the relatively high content of volatile matter is undoubtedly due, in part at least, to dehydration of clayey substances and decomposition of carbonates present in the ash.

Analyses of residue in 3500 c. c. retort.

No. of sample	Test No.	Maximum temperature reached on recorder, ° F.	Character of sample	Character of residue	Moisture	Volatile matter	Fixed carbon	Ash	Nitrogen	Sulphur
35.	1	1,400	Cannel coal, Upper Kittauning	Slight tendency to cake	.5	2.6	52.7	44.2	.52	1.82
35.	2	900	do.	Slight tendency to cake	.5	7.0	51.7	40.8	1.01	1.32
44.	1	1,400	Bituminous coal, Upper Freeport	Hard, porous coke	1.1	2.4	82.8	13.7	.93	1.50
93.	1	1,400	Bituminous coal, Brookville	Hard, porous coke	.8	3.8	80.2	15.2	1.08	3.81
93.	2	900	do.	Hard, porous coke	.7	13.0	72.9	13.4	1.45	4.52
98.	1	1,400	Bituminous coal, Pittsburgh	Hard, porous coke	1.1	5.0	81.1	12.8	1.20	2.03
98.	2	900	do.	Hard, porous coke	1.0	9.4	77.7	11.9	1.51	2.17
102.	1	1,400	Cannel shale, Lower Freeport	No tendency to cake	.6	.6	32.4	66.4	.28	1.06
102.	2	900	do.	No tendency to cake	.7	6.1	28.8	64.4	.47	1.60
105.	1	1,400	Bituminous coal, Upper Freeport	Hard, porous coke	.8	3.3	80.2	15.7	1.25	1.17
105.	2	900	do.	Hard, porous coke	1.3	9.9	77.2	11.6	1.66	1.17
106.	2	1,400	Bone, Upper Freeport	Tendency to cake	.9	3.0	46.8	49.3	.54	1.00
106.	4	1,400	do.	Tendency to cake	.9	2.1	48.6	48.4	.50	.82
107.	1	1,400	Cannel shale, Upper Freeport	Slight tendency to cake	1.0	1.7	53.8	43.5	.79	1.82
107.	2	1,400	do.	Slight tendency to cake	.4	3.9	50.1	45.6	.76	2.21
110.	1	1,400	Oil shale, Chattanooga	No tendency to cake	.5	4.2	6.1	89.2	.25	1.72
110.	2	900	do.	No tendency to cake	.4	18.8	4.6	76.2	.59	1.51
115.	1	1,400	Oil shale, Green River, Eocene	Slight tendency to cake	.4	4.7	.9	94.0	.09	1.27
115.	3	900	do.	Slight tendency to cake	.3	20.6	1.6	77.5	.41	1.32
122.	1	1,400	Oil shale, Miocene	No tendency to cake	.3	3.7	8.0	88.0	.18	3.40

Composition of gas from carbonization tests in 3500 c. c. retort, in per cent by volume.

Number and description of sample	Temperature at which sample was taken (°F.)	Carbon dioxide also including H_2S and SO_2	Unsaturated hydrocarbons	Oxygen	Carbon monoxide	Methane	Hydrogen	Nitrogen
Test 35-1								
Cannel coal, Upper Kittanning	650	6.9	3.8	0.2	2.7	66.5	11.2	8.6
do.	950	2.7	0.2	0.1	6.6	33.3	38.0	19.0
do.	1250	0.0	0.0	0.1	6.9	12.9	61.4	18.6
Test 35-2								
Cannel coal, Upper Kittanning	600	9.9	4.4	0.1	2.6	70.9	10.1	2.0
do.	900	6.3	2.3	0.2	3.4	51.7	32.6	3.4
Test 44-1								
Bituminous coal, Upper Freeport	650	4.2	2.0	0.2	3.5	62.2	18.9	9.0
do.	950	.6	0.0	0.1	5.2	27.9	48.3	17.9
do.	1250	0.0	0.0	0.2	3.9	9.1	61.3	25.5
Test 93-1								
Bituminous coal, Brookville	650	12.1	1.6	0.2	4.8	57.4	12.7	11.2
do.	950	8.5	0.2	0.1	5.8	31.5	52.8	1.2
do.	1250	0.2	0.0	0.1	5.3	14.1	73.5	6.8
Test 93-2								
Bituminous coal, Brookville	600	10.6	2.4	0.1	3.9	36.9	17.2	28.8
do.	900	8.2	2.0	0.1	5.6	51.7	30.4	2.0
Test 98-1								
Bituminous coal, Pittsburgh	650	8.5	1.3	0.1	3.9	79.4	0.7	6.2
do.	950	2.3	0.2	0.1	6.4	31.9	57.5	1.6
do.	1250	1.6	0.0	0.1	14.6	17.7	70.9	15.0
Test 102-1								
Cannel shale, Lower Freeport	650	15.3	1.4	0.3	2.4	43.2	28.5	8.9
do.	950	8.7	0.4	0.2	5.9	29.9	40.8	14.1
do.	1250	2.4	0.0	0.2	17.1	12.4	38.8	29.1
Test 102-2								
Cannel shale, Lower Freeport	600	13.9	3.0	0.2	3.1	41.3	26.4	11.9
do.	900	9.1	0.8	0.1	8.8	26.2	33.2	21.8

Composition of gas from carbonization tests in 3500 c. c. retort, in per cent by volume (Cont'd.)

Number and description of sample	Temperature at which sample was taken (°F.)	Carbon dioxide also including H_2S and SO_2	Unsaturated hydrocarbons	Oxygen	Carbon monoxide	Methane	Hydrogen	Nitrogen
Test 105-1								
Bituminous coal, Upper Freeport	650	2.7	3.0	0.1	3.6	64.4	19.3	6.9
do.	1250	0.0	0.0	0.5	2.2	10.9	75.0	11.4
Test 106-4								
Bone, Upper Freeport ------------	650	4.0	2.4	0.1	3.8	54.1	32.7	2.9
do.	950	2.2	0.1	0.1	5.2	29.9	50.2	12.3
do.	1250	0.0	0.0	0.1	2.8	10.2	75.8	11.1
Test 107-1								
Cannel shale, Upper Freeport --	650	3.7	1.2	0.2	1.4	70.4	7.9	15.2
do.	950	2.6	0.5	0.3	3.1	45.3	30.9	17.3
do.	1250	0.5	0.0	0.1	5.5	13.5	68.2	12.2
Test 107-2								
Cannel shale, Upper Freeport ----	650	7.0	3.7	0.2	1.9	68.4	11.9	6.0
do.	950	4.0	2.3	0.1	5.2	32.1	49.9	6.5
do.	1250	0.1	0.0	0.2	7.6	8.0	78.6	5.6
Test 110-1								
Oil shale, Chattanooga ----------	650	25.6	2.6	0.1	4.1	48.0	15.3	4.3
do.	950	43.2	0.4	0.1	21.7	12.6	17.8	4.1
do.	1250	28.1	0.0	0.1	51.8	0.7	4.6	14.6
Test 110-2								
Oil shale, Chattanooga ----------	600	23.0	0.7	0.1	2.3	43.5	16.8	13.7
do.	900	40.1	0.6	0.2	12.5	21.1	20.1	5.5
Test 115-1								
Oil shale, Green River ----------	650	19.6	5.4	0.2	3.9	52.7	15.7	2.5
do.	950	49.5	0.5	0.1	19.9	12.2	5.0	12.7
do.	1250	32.5	0.0	0.1	53.1	2.3	6.7	5.2
Test 115-2								
Oil shale, Green River -----------	600	17.2	4.6	0.1	5.6	42.5	17.8	12.3
do.	900	37.5	1.3	0.1	21.9	14.5	11.0	13.7
Test 115-3								
Oil shale, Green River ------------	600	23.7	1.9	0.2	4.3	46.6	13.3	10.0
do.	900	34.8	2.8	0.2	21.7	21.2	12.3	6.9
Test 122-1								
Oil shale, Miocene ----------------	650	36.8	0.8	0.1	5.1	19.9	27.4	10.0
do.	950	22.1	0.6	0.1	7.2	28.0	32.6	9.3
do.	1250	4.3	0.1	0.1	40.3	6.8	32.3	16.1

CHAPTER VIII.

COMPOSITION OF OILS AND TARS.

The specific gravities of all the oils and tars obtained from the carbonization tests were determined by the use of specific gravity bottles, as already described, and recorded in the tables given in Chapter VII. The water, nitrogen, and sulphur contents of the oils and tars obtained from the carbonization tests in the 3500 c. c. retort, were also determined and the data likewise assembled in Chapter VII. The latter oils and tars were then fractioned and the fractions treated with 10 per cent sodium hydroxide solution and 20, 95, and 98 per cent sulphuric acid, in order to determine their content of tar acids and bases and of saturated and unsaturated hydrocarbon constituents.

The water content of the oils and tars was determined by distillation up to 170° C. Considerable care had to be exercised in conducting this operation in order to prevent excessive foaming. The oil or tar was placed in a copper tar still with a ½-inch glass tube bent into an inverted U serving as an outlet for the vapors. This tube was connected with a 16-inch 5-bulb water cooled Allihn condenser. The distillate was caught in a graduated cylinder. The copper still was placed in an electric drying oven with the outlet tube projecting through the top. The temperature was gradually raised to 170° C. and maintained at that point for about four hours. The volume of water in the graduated cylinder was then read, the contents poured into a separatory funnel, the water drawn off, and light oils, which distilled off with it were returned to the oil or tar in the still. The latter was thoroughly shaken so as to insure an intimate mixture.

The total nitrogen present in the oils or tars was determined by the Kjeldahl-Gunning method, following exactly the same procedure as in the case of the coal and shale samples. The sulphur content was determined by means of a Parr heat ignition sulphur bomb, the method being as follows:— One gram of finely pulverized potassium chlorate was first placed in the fusion cup of the bomb. To this 10 grams of pure sulphur-free sodium peroxide and approximately .2 gram of benzoic acid were added. The three were thoroughly mixed. From .3 to .5 gram of oil or tar was then weighed by means of a 1 c. c. specific gravity bottle and added to the mixture. The whole was then thoroughly mixed by stirring with a long glass rod. After the cover had been securely fastened in place by means of a screw cap, ignition was produced by holding the bottom of the fusion cup in the tip of a Bunsen burner flame with a pair of long tongs. The bomb was then cooled by submergence in water, the cover removed, and the inside carefully rinsed into a 400 c. c. beaker. The cup itself was placed in the same beaker and 75 c. c. of water were added. After solution was completed, the cup was removed and thoroughly rinsed. The contents of the beaker were then carefully neutralized with concentrated hydrochloric acid. About 5 c. c. of saturated bromine water was next added to completely oxidize all the sulphur and iron. The solution was then made alkaline with ammonia and brought to a vigorous boil to coagulate the precipitated ferric hydroxide and expell the excess ammonia. The former was filtered off and thoroughly washed with hot water. The filtrate was acidulated with 1 c. c. of concentrated hydrochloric acid and diluted to about 250 c. c. The solution was then brought to a boil and 5 c. c. of 10 per cent barium chloride solution was slowly added from a burette. The solution was kept nearly at boiling temperature for two hours and was then allowed to stand over night before the barium sulphate was filtered off, ignited, and weighed. A blank determination was made, using exactly the same chemicals as above but no oil or tar. The correction factor was found to be negligible.

For the analytical distillation of the oils and tars, a No. 26 Pyrex distillation flask was used, as is recommended by the U. S. Bureau of Mines for petroleum distillation.[1] Heat was applied by means of a Cenco electric heater with a beveled opening $2\frac{1}{2}$ inches in diameter in which the bottom of the flask rested. The flask and neck were surrounded by an asbestos shield. For measuring temperatures, a nitrogen-filled thermometer reading to 400° C. graduated in degrees, was employed. The 40-degree mark just projected above the top of the cork. No correction for emergent stem was made. During distillations at atmospheric pressure the neck of the flask up to the side outlet was filled with iron "jack" chain supported on a wire spring clip. For condensing the vapors from the flask a 12-inch water cooled condenser of the Allihn type with three bulbs was used. For vacuum distillations the same apparatus was employed. A 100 c. c. graduated cylinder with side tube was attached to the bottom of the condenser, as shown in figure 15.

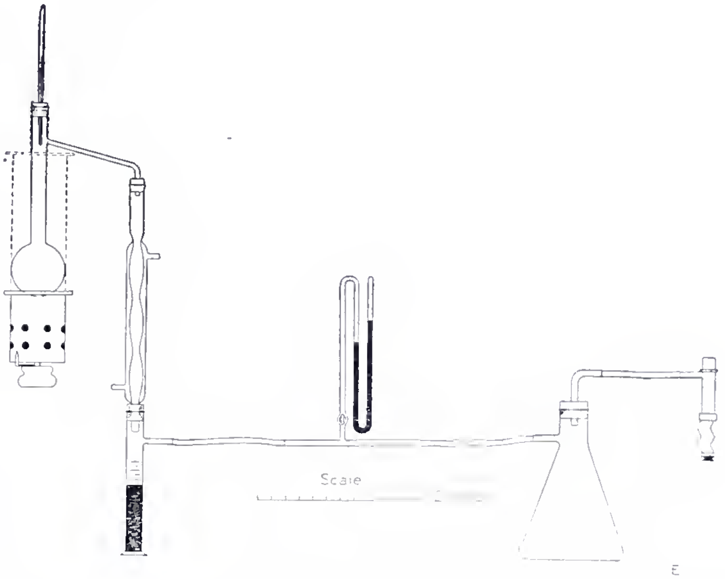

Fig. 15. Diagram showing distillation apparatus set up for obtaining vacuum fraction.

This was connected with a Richard filter pump. A mercury manometer was placed on the line leading to the vacuum pump to record pressures.

In carrying out the distillation tests, 300 c. c. of oil or tar were weighed into the flask. The weight in grams required was determined by multiplying 300 by the specific gravity of the oil or tar as previously determined. The cork carrying the thermometer and the one at the top of the condenser were luted in place by a thick paste of dried litharge and glycerine. The temperature was read as soon as the first drop fell from the condenser, and volumes of oil distilled off were recorded thereafter at every point that was a multiple of 25° C. The distillation was first conducted at atmospheric pressure and carreid to 275° C. Two sets of tests were carried out. In the first, all the fractions below 200° C. were combined, and those from 200 to 275° C. In the second, the fractions below 175° C. were combined, then those from 175° to 225°, and finally those from 225° to 275°.

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[1] Dean, E. W., Hill, H. H., Smith, N. A. C., and Jacobs, W. A. The analytical distillation of petroleum and its products. U. S. Bureau of Mines, Bull. 207, p. 9, 1922.

After the distillation had been carried to 275° C., the heat was turned off, and the residue allowed to cool. In the meantime, the apparatus was connected with the water aspirator. The iron "jack" chain was removed from the neck of the flask and three conical shaped gauze spray catchers were introduced. Heat was again applied and the pressure was reduced to as nearly 40 millimeters of mercury as was possible with the type of vacuum pump employed. Distillation under vacuum was carried to 300° C. During the latter part of the distillation, water which had been raised nearly to the boiling point was circulated through the condenser in order to prevent the separation of paraffin wax from the distillate. In the first set of tests only the total volume of distillate was determined. In the second set, volume readings were taken at multiple points of 25° C.

The specific gravities at 60° F (15.56° C.) of the various fractions into which the oil was separated were determined by the use of specific gravity bottles of the type already mentioned in Chapter VI.

In the first set of distillations, the oil or tar was separated into four fractions:—(1) that which distilled off below 200° C. at atmospheric pressure; (2) that which came off between 200° and 275°; (3) that which was distilled below 300° under vacuum from the remainder; and (4) the residue. The fractions obtained by distillation at atmospheric pressure were treated with concentrated sulphuric acid (95 per cent)[1] and 10 per cent sodium hydroxide solution, separate portions of the crude distillate being taken for each treatment.

In the second set of distillations, the oil or tar was separated into five parts:—(1) that which distilled off below 175° C; (2) that between 175° and 225°; (3) that between 225° and 275° at atmospheric pressure; (4) that which was distilled off under vacuum below 300° from the remainder; and (5) the residue. The fractions obtained at atmospheric pressure were first treated with a 10 per cent solution of sodium hydroxide to determine their content of tar acids, and then with 20 per cent sulphuric acid solution to obtain the percentage of tar bases present. After this treatment, the neutral oil remaining was divided into two parts, one of which was treated with concentrated sulphuric acid (95 per cent) and the other with 37 normal sulphuric acid (98 per cent). The residue from the latter treatment represents the saturated hydrocarbon constituents of the fraction and consists of paraffin and napthene hydrocarbons. The carbon residue of the pitch from the vacuum distillation was determined by the Conradson method.

For the treatment with 10 per cent sodium hydroxide and 20 per cent sulphuric acid solutions, a separatory funnel was employed. The funnel was glass stoppered and equipped with a glass stop-cock. The long stem was graduated from 0 to 20 c. c. in 1/10 c. c. divisions. The stem was filled nearly to the 20 c. c. mark with the oil fraction to be tested and immersed in a water bath held at 60°C. About 15 minutes were allowed for the oil to come to the temperature of the bath. The volume of the oil was then adjusted so that exactly 20 c. c. remained in the funnel at this temperature. 30 c. c. of 10 per cent sodium hydroxide solution were then added and the mixture thoroughly agitated for 5 minutes. 15 minutes in the water bath were then allowed for settling to take place, at the end of which the sodium hydroxide solution was withdrawn. If the latter solution was appreciably discolored, the treatment was repeated. At the end of the operation, the volume of the residual oil at 60° C. was read. It is generally considered that those constituents which go into solution in the sodium hydroxide solution represent tar acids or phenols. Some recent investigators, however, have been lead to believe that in the case of the low-temperature coal tars, even in those fractions which distill below 275°C., some tar resins of an asphaltene character, which are soluble in sodium hydroxide solution, may also be present.

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[1] The concentrated sulphuic acid obtained from manufactures varies slightly and in this instance I actually determined the sulphuric acid content.

The treatment with sodium hydroxide was followed by a treatment with a 20 per cent sulphuric acid solution, the method of precedure being exactly the same. One treatment was deemed sufficient. This solution takes out the tar or nitrogen bases.

The residual neutral oils in the separatory funnel consist of hydrocarbon compounds, belonging to the following groups:—

Unsaturated (olefinic and cylic)
Aromatic (liquid)
Naphthene (saturated cyclic)
Paraffin (liquid and solid)

The neutral oil was divided into two parts, one of which was treated with concentrated sulphuric acid (95 per cent) and the other with 37 normal sulphuric acid (98 per cent). The residue from the latter treatment represents the naphthene and paraffin hydrocarbons present in the neutral oil. The treatment with concentrated sulphuric acid was included because that is the strength of acid commonly employed in determining the percentage of unsaturated hydrocarbons present in petroleum products.

For the treatment with the 95 per cent sulphuric acid, a 6-inch, 9-gram, 40 per cent Babcock cream bottle was employed. The graduated portion of the neck had a volume of 4.9 c. c. and this volume of oil, therefore, was employed for the test. It was delivered to the bottle by means of a calibrated pipette; 10 c. c. of concentrated acid were then added by carefully introducing the acid to the side of the bottle. A rubber stopper was inserted and the contents shaken, for several minutes first slowly and then vigorously with a rotary motion. Concentrated sulphuric acid was then added to bring the level of the liquid to the neck of the bottle, after which the bottle was immersed in hot water (60° C.) for several minutes and centrifuged for about three minutes. More acid was then added until the lower level of the supernatant oil was plainly visible above the lowest graduation mark. The centrifuging was repeated for another two minutes, after which the volume of residual oil was read. In the case of the oils distilling below 175° C. the immersion in hot water was omitted.

The same type of Babcock bottle and a similar volume of oil were used for the treatment with the 98 per cent acid. The latter was prepared by mixing previously analyzed 95 per cent and fuming sulphuric acid in the proper proportions. 10 c. c. of this acid were added to the oil in the Babcock bottle and shaken for two minutes after which 10 c. c. more were added and the shaking repeated. The bottle was then kept at a temperature of 98 to 100° C. for one hour in an electric drying oven, during which time it was shaken vigorously every 10 minutes. Before shaking, it was immersed in cold water to prevent excessive foaming. In the cases of oils which distilled below 175° C. the heating was omitted. At the end of the hour the bottle was cooled, filled to the neck with concentrated sulphuric acid and centrifuged for three minutes. More acid was then added to bring the lower level of the supernatant oil above the lowest graduation mark, and the centrifuging continued for another two minutes. The volume of residual was then read. No correction was made for polymerization.

During the present investigation, only the specific gravity of the vacuum fraction was determined. In the case of the residuum from the vacuum distillation, the specific gravity and carbon residue were obtained. The latter was determined by the well-known Conradson method, using those modifications suggested by the U. S.

Bureau of Mines.[1] This test is applied, in the case of petroleum, to determine whether a given crude will yield a good grade of cylinder stock. According to Dean,[2] the residuums of all of the crudes that experience has shown to be suitable material for cylinder stock, when refined according to present conventional practice, have low carbon residues, generally from 1 to 3 per cent.

The tables which follow give the results of the distillation analyses and tests made upon the oils and low-temperature tars obtained from the carbonization tests in the 3500 c. c. retort.

Oil from Test 35-1, Cannel coal, Upper Kittanning.

Specific gravity of dehydrated oil, .9519
Sulphur .... .38 per cent.
Nitrogen .... .71 per cent.

Distillation record.

Air distillation, barometer 28.890 in., first drop, 42° C.

Temperature Degrees C.	Per cent by volume distilled	Sum, per cent	Per cent cut	Sp. gr. cut	Crude distillate removed by 95% H_2SO_4 per cent	Crude distillate removed by 10% NaOH per cent
To 50	trace	trace	21.21	.8071	36	10.8
50 to 75	1.87	1.87				
75 to 100	.87	2.74				
100 to 125	3.20	5.94				
125 to 150	4.87	10.81				
150 to 175	4.00	14.81				
175 to 200	6.40	21.21				
200 to 225	6.33	27.54	21.13	.9112	54	14.7
225 to 250	6.33	33.87				
250 to 275	8.47	42.34				
Vacuum distillation at 33 millimeters						
to 300			44.20	.9930		
Residuum by difference			13.46			

Equal quantities of low-temperature tar from Tests 98-1 and 98-2, Bituminous coal, Pittsburgh.

Specific gravity of dehydrated tar, 1.0329
Sulphur .... .88 per cent.
Nitrogen .... .82 per cent.

Distillation record.

Air distillation, barometer 29.906 in., first drop 39° C.

Temperature Degrees C.	Per cent by volume distilled	Sum, per cent	Per cent cut	Sp. gr. cut	Crude distillate removed by 95% H_2SO_4 per cent	Crude distillate removed by 10% NaOH per cent
To 50	trace	trace	21.38	.8934	66	30.8
50 to 75	1.27	1.27				
75 to 100	2.27	3.54				
100 to 125	1.07	4.61				
125 to 150	2.27	6.88				
150 to 175	3.87	10.75				
175 to 200	10.63	21.38				
200 to 225	8.80	30.18	28.27	.9677	85	38.4
225 to 250	10.67	40.85				
250 to 275	8.80	49.65				
Vacuum fraction at 31 millimeters						
To 300			28.33	1.0645		
Residuum by difference			22.02			

Oil from Test 102-1, Cannel shale, Lower Freeport.

Specific gravity of dehydrated oil, .8811
Sulphur .... .32 per cent.
Nitrogen .... .45 per cent.

Distillation record.

Air distillation, barometer 28.928 in., first drop 45° C.

Temperature Degrees C.	Per cent by volume distilled	Sum, per cent	Per cent cut	Sp. gr. cut	Crude distillate removed by 95% H_2SO_4 per cent	Crude distillate removed by 10% NaOH per cent
To 50	trace	trace	19.21	.7720	30.5	2.5
50 to 75	.67	.67				
75 to 100	1.47	2.14				
100 to 125	3.00	5.14				
125 to 150	4.00	9.14				
150 to 175	4.20	13.34				
175 to 200	5.87	19.21				
200 to 225	5.37	24.58	20.67	.8395	30.5	3.2
225 to 250	5.90	30.48				
250 to 275	9.40	39.88				
Vacuum fraction at 37 millimeters						
To 300			36.33	.9064		
Residuum by difference			23.79			

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[1] Dean. E. W., et al; op. cit. pp. 34-35.

[2] Dean. E. W. Properties of typical crude oils from the eastern producing fields of the United States. U. S. Bureau of Mines. Reports of Investigations, Serial No. 2202. p. 7, 1921.

Equal amounts of oil from Tests 110-1 and 110-2. Oil shale, Chattanooga.

Specific gravity of dehydrated oil, .9232
Sulphur .... 1.52 per cent.
Nitrogen .... 1.20 per cent.

Distillation record.

Air distillation, barometer 29.320 in., first drop 51° C.

Temperature Degrees C.	Per cent by volume distilled	Sum, per cent	Per cent cut	Sp. gr. cut	Crude distillate removed by 95% H_2SO_4 per cent	Crude distillate removed by 10% NaOH per cent
To 50	none	none	24.87	.8017	40	1.3
50 to 75	.67	.67				
75 to 100	1.53	2.20				
100 to 125	3.87	6.07				
125 to 150	5.20	11.27				
150 to 175	7.07	18.34				
175 to 200	6.53	24.87				
200 to 225	6.87	31.74	21.90	.8893	54	5.8
225 to 250	7.73	39.47				
250 to 275	7.30	46.77				
Vacuum fraction at 33 millimeters						
To 300			38.20	.9707		
Residuum by difference			15.03			

Equal amounts of oil from Tests 115-1 and 115-3, Oil shale, Green River Eocene.

Specific gravity of dehydrated oil, .8889
Sulphur .... .60 per cent.
Nitrogen .... 1.86 per cent.

Distillation record.

Air distillation, barometer 28.876 in., first drop 40° C.

Temperature Degrees C.	Per cent by volume distilled	Sum, per cent	Per cent cut	Sp. gr. cut	Crude distillate removed by 95% H_2SO_4, per cent	Crude distillate removed by 10% NaOH per cent
To 50	.03	.03	22.06	.7826	42	.6
50 to 75	1.10	1.13				
75 to 100	1.47	2.60				
100 to 125	3.20	5.80				
125 to 150	4.53	10.33				
150 to 175	8.33	18.66				
175 to 200	3.40	22.06				
200 to 225	7.13	29.19	23.16	.8676	54	1.6
225 to 250	5.13	34.32				
250 to 275	10.90	45.22				
Vacuum fraction at 36 millimeters						
To 300			38.83	.9256		
Residuum by difference			15.95			

Oil from Test 35-2, Cannel coal, Upper Kittanning.

Specific gravity of dehydrated oil, .9452
Sulphur .... .32 per cent.
Nitrogen .... .73 per cent.

Distillation record.

Air distillation, barometer 29.114 in., first drop 44° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	trace	trace	15.44	.7753
50 to 75	1.33	1.33		
75 to 100	1.07	2.40		
100 to 125	3.80	6.20		
125 to 150	4.47	10.67		
150 to 175	4.77	15.44		
175 to 200	5.93	21.37	13.43	.8730
200 to 225	7.50	28.87		
225 to 250	6.40	35.27	13.80	.9137
250 to 275	7.40	42.67		
Vacuum distillation at 45 millimeters				
To 200	4.33	4.33	40.00	.9731
200 to 225	8.00	12.33		
225 to 250	8.67	21.00		
250 to 275	8.67	29.67		
275 to 300	10.33	40.00		
Residuum by difference			17.33	1.0806

Carbon residue of residuum (Conradson method) 11.0 per cent.

Composition of air distillation fractions from oil 35-2, in per cent by volume.

Fraction Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal		.6982	0.0	0.3	99.7	24.2	39.6	60.2
To 175	15.44	.7753	4.8	0.5	94.7	29.0	44.6	52.5
175 to 225	13.43	.8730	21.8	2.8	75.4	30.0	52.0	36.1
225 to 275	13.80	.9137	15.0	5.5	79.5	37.0	61.0	31.0

Low temperature tar from Tests 93-1 and 93-2. Bituminous coal, Brookville.

Specific gravity of dehydrated tar, 1.0166

Sulphur .... .51 per cent.

Nitrogen .... .73 per cent.

Distillation record.

Air distillation, barometer 29.258 in., first drop 52° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	none	none	12.27	.8317
50 to 75	1.53	1.53		
75 to 100	2.07	3.60		
100 to 125	1.40	5.00		
125 to 150	3.50	8.50		
150 to 175	3.77	12.27		
175 to 200	8.83	21.10	21.36	.9599
250 to 275	6.90	48.96		
225 to 250	8.43	42.06	15.33	.9864
250 to 275	6.90	48.96		
Vacuum distillation at 44 millimeters				
To 200	3.00	3.00	31.67	1.0419
200 to 225	6.67	9.67		
225 to 250	6.00	15.67		
250 to 275	7.67	23.34		
275 to 300	8.33	31.67		
Residuum by difference			19.37	1.1441

Carbon residue of residuum (Conradson method) 22.8 per cent.

Composition of air distillation fractions from low-temperature tars 93-1 and 93-2, in per cent by volume.

Fraction Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal		.7199	.2	.8	99.0	29.8	50.8	48.7
To 175	12.27	.8317	13.3	1.5	85.2	39.0	59.0	34.9
175 to 225	21.36	.9599	51.8	2.0	46.2	47.0	65.0	16.2
225 to 275	15.33	.9864	37.0	3.5	59.5	56.0	77.6	13.3

Oil from Test 102-2, Cannel shale, Lower Freeport.

Specific gravity of dehydrated oil, .8790

Sulphur .... .33 per cent...

Nitrogen .... .48 per cent.

Distillation record.

Air distillation, barometer 29.316 in., first drop 51° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	none	none	13.8	.7524
50 to 75	.9	.9		
75 to 100	1.1	2.0		
100 to 125	3.4	5.4		
125 to 150	4.0	9.4		
150 to 175	4.4	13.8		
175 to 200	5.2	19.0	11.3	.8105
200 to 225	6.1	25.1		
225 to 250	6.8	31.9	14.8	.8414
250 to 275	8.0	39.9		
Vacuum distillation at 46 millimeters				
To 200	4.7	4.7	37.1	.8960
200 to 225	5.7	10.4		
225 to 250	8.3	18.7		
250 to 275	8.7	27.4		
275 to 300	9.7	37.1		
Residuum by difference			23.0	.9550

Carbon residue of residuum (Conradson method) 4.3 per cent.

Composition of air distillation fractions from Oil 102-2, in per cent by volume.

Fraction, Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal		.6887	.6	.3	99.1	24.0	40.8	58.7
To 175	13.8	.7524	1.5	.5	98.0	24.0	43.5	55.4
175 to 225	11.3	.8105	5.5	1.0	93.5	24.0	46.0	50.5
225 to 275	14.8	.8414	3.8	1.8	94.4	27.0	50.0	47.2

Low-temperature tar from Tests 105-1 and 105-2 Bituminous coal, Upper Freeport.

Specific gravity of dehydrated tar, 1.0072
Sulphur .... .47 per cent.
Nitrogen .... .72 per cent.

Distillation record.

Air distillation, barometer 29.150 in., first drop 45° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	trace	trace	11.40	.8233
50 to 75	.80	.80		
75 to 100	1.47	2.27		
100 to 125	2.33	4.60		
125 to 150	2.73	7.33		
150 to 175	4.07	11.40		
175 to 200	8.33	19.73	18.66	.9357
200 to 225	10.33	30.06		
225 to 250	6.00	36.06	13.67	.9592
250 to 275	7.67	43.73		
Vacuum distillation at 52 millimeters				
To 200	4.00	4.00	31.33	1.0129
200 to 225	5.67	9.67		
225 to 250	6.33	16.00		
250 to 275	7.33	23.33		
275 to 300	8.00	31.33		
Residuum by difference.			24.94	1.1272

Carbon residue of residuum (Conradson method) 18.5 per cent.

Composition of air distillation fractions from low-temperature tars 105-1 and 105-2, in per cent by volume.

Fraction, Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal		.7282	.8	1.0	98.2	25.0	43.4	55.6
To 175	11.40	.8233	12.5	1.0	86.5	33.0	49.0	44.1
175 to 225	18.66	.9357	45.3	1.5	53.2	37.6	58.0	22.3
225 to 275	13.67	.9592	28.3	3.3	68.4	51.0	67.0	22.6

Low-temperature tar from Tests 106-2, 106-3, and 106-4. Bone, Upper Freeport.

Specific gravity of dehydrated tar, 1.0062
Sulphur .... .40 per cent.
Nitrogen .... .79 per cent.

Distillation record.

Air distillation, barometer 29.144 in., first drop 45° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	trace	trace	12.50	.8187
50 to 75	.67	.67		
75 to 100	2.60	3.27		
100 to 125	2.33	5.60		
125 to 150	2.07	7.67		
150 to 175	4.83	12.50		
175 to 200	10.27	22.77	19.60	.9357
200 to 225	9.33	32.10		
225 to 250	7.87	39.97	17.60	.9655
250 to 275	9.73	49.70		
Vacuum distillation at 45 millimeters				
To 200	3.67	3.67	31.34	1.0381
200 to 225	3.67	7.34		
225 to 250	7.33	14.67		
250 to 275	7.00	21.67		
275 to 300	9.67	31.34		
Residuum by difference.			18.96	1.1414

Carbon residue of residuum (Conradson method) 19.5 per cent.

Composition of air distillation fractions from low-temperature tars 106-2, 106-3 and 106-4, in per cent by volume.

Fraction, Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal	----------	.7324	.8	1.0	98.2	26.4	44.4	54.6
To 175	12.50	.8187	11.7	.7	87.6	31.0	49.0	44.7
175 to 225	19.60	.9357	43.1	1.0	55.9	37.0	59.0	22.9
225 to 250	17.60	.9655	26.5	3.1	70.4	57.0	71.0	20.4

Composition of air distillation fractions from oil 107-1, in per cent by volume.

Fraction, Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal	----------	.7055	.2	.3	99.5	23.0	37.0	62.7
To 175	18.20	.7725	7.3	1.0	91.7	25.6	40.0	55.0
175 to 225	11.87	.8472	16.2	1.6	82.2	23.0	40.0	49.3
225 to 275	20.14	.8706	8.9	2.8	88.3	24.0	44.0	49.4

Oil from Test 107-1, Cannel shale, Upper Freeport.

Specific gravity of dehydrated oil, .8975

Sulphur .... .55 per cent.

Nitrogen .... .62 per cent.

Distillation record.

Air distillation, barometer 29.120 in., first drop 45° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	.27	.27		
50 to 75	1.13	1.40		
75 to 100	2.20	3.60	18.20	.7725
100 to 125	2.80	6.40		
125 to 150	4.93	11.33		
150 to 175	6.87	18.20		
175 to 200	4.80	23.00	11.87	.8472
200 to 225	7.07	30.07		
225 to 250	8.07	38.14	20.14	.8706
250 to 275	12.07	50.21		
Vacuum distillation at 48 millimeters				
To 200	1.33	1.33		
200 to 225	4.33	5.66		
225 to 250	10.33	15.99	33.32	.9108
250 to 275	8.33	24.32		
275 to 300	9.00	33.32		
Residuum by difference			16.47	1.0054

Carbon residue of residuum (Conradson method) 7.6 per cent.

Oil from Test 115-2, Oil Shale, Green River Eocene.

Specific gravity of dehydrated oil, .8864

Sulphur .... .60 per cent.

Nitrogen .... 1.86 per cent.

Distillation record.

Air distillation, barometer 29.098 in., first drop 45° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	trace	trace		
50 to 75	.90	.90		
75 to 100	.70	1.60	16.50	.7649
100 to 125,	3.40	5.00		
125 to 150	4.53	9.53		
150 to 175	6.97	16.50		
175 to 200	5.00	21.50	10.80	.8246
200 to 225	5.80	27.30		
225 to 250	9.40	36.70	18.67	.8645
250 to 275	9.27	45.97		
Vacuum distillation at 49 millimeters				
To 200	2.00	2.00		
200 to 225	6.67	8.67		
225 to 250	8.33	17.00	36.20	.9106
250 to 275	10.00	27.00		
275 to 300	9.20	36.20		
Residuum by difference			17.83	.9500

Carbon residue of residuum (Conradson method) 5.4 per cent.

Compposition of air distillation fractions from Oil 115-2, in per cent by volume.

Fraction, Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydro carbons (Naphthene and paraffin) in fraction
Light oil from charcoal		.6910	0.0	.8	99.2	30.4	47.6	52.0
To 175	16.50	.7649	0.5	3.8	95.7	32.0	49.0	48.8
175 to 225	10.80	.8246	3.0	10.3	86.7	36.0	53.5	40.3
225 to 275	18.67	.8645	1.8	12.5	85.7	42.5	57.0	36.9

Composition of air distillation fractions from Oil 122-1, in per cent by volume.

Fraction, Degrees C.	Crude oil	**Sp. gr. fraction at 15.56° C.**	Tar acid removed by 10% NaOH	Tar bases removed by 20% H_2SO_4	Neutral oil in fraction	Neutral oil removed by 95% H_2SO_4	Neutral oil removed by 37 N H_2SO_4	Saturated hydrocarbons (Naphthene and paraffin) in fraction
Light oil from charcoal		.7178	.3	1.0	98.7	22.0	52.0	47.4
To 175	13.00	.7862	3.5	1.5	95.0	34.6	56.0	41.8
175 to 225	12.86	.8467	8.5	2.8	88.7	35.0	54.4	40.4
225 to 275	13.40	.8675	7.6	2.5	90.0	41.6	58.6	37.3

Oil from Test 122-1, Oil Shale, Miocene.

Specific gravity of dehydrated oil, .8893

Sulphur .... .99 per cent.

Nitrogen .... .65 per cent.

Distillation record.

Air distillation, barometer 29.300 in., first drop 60° C.

Temperature Degrees C.	Per cent by volume distilled	Sum per cent	Per cent cut	Sp. gr. cut
To 50	none	none	13.00	.7862
50 to 75	.47	.47		
75 to 100	2.33	2.80		
100 to 125	2.60	5.40		
125 to 150	3.40	8.80		
150 to 175	4.20	13.00		
175 to 200	5.73	18.73	12.86	.8467
200 to 225	7.13	25.86		
225 to 250	6.67	32.53	13.40	.8675
250 to 275	6.73	39.26		
Vacuum distillation at 42 millimeters				
To 200	5.00	5.00	36.37	.8956
200 to 225	7.00	12.00		
225 to 250	7.67	19.67		
250 to 275	7.67	27.34		
275 to 300	9.33	36.67		
Residuum by difference			24.07	.9453

Carbon residue of residuum (Conradson method) 7.1 per cent.

Study of the composition of the oils and low-temperature tars prepared in the 350 c. c. retort brought out some interesting resemblances and differences. The low-temperature tars from bituminous coals almost invariably had higher specific gravities than the oils obtained from any cannel coals and shales or oil shales when the same conditions of carbonization were maintained. This also held true for the corresponding fractions, the difference being least in the case of the light oils recovered from the activated charcoal. Although all the oils examined contained tar acids or phenols, in at least small quantities these compounds were particularly characteristic of the low-temperature tars obtained from bituminous coal. The middle fraction, that from 175 to 225° C. contained the largest quantities. These quantities exceeded 50 per cent by volume in the case of some of the low temperature tars. The tar or nitrogen bases, with the exception of the Colorado shale oil, were found to be of only minor importance as far as volume was concerned. The fraction from 225 to 275° C. contained the greatest quantity. The oil obtained from the Green River oil shale of Colorado differed from the others examined in the phenomenally low content of phenols and high percentage of nitrogen bases that were present. The lighter fractions were always found to contain the highest percentage of saturated hydrocarbons, the difference being most pronounced in the case of the fractions derived from the low-temperature tars from bituminous coal.

The present investigation was undertaken primarily for the purpose of determining the possibilities of obtaining substitutes for petroleum products through the development of a low-temperature carbonization industry in Pennsylvania. It has been shown that bituminous coals are the only raw materials present in the State in sufficiently large quantities to support an extensive industry of this character. As has been pointed out in a previous chapter, motor fuels, fuel oils, lubricants, and illuminating oils are petroleum products that are in greatest demand. The low-temperature tars derived from Pennsylvania bituminous coals are so different in composition from crude petroleum that the ordinary methods of petroleum refining are not applicable and a new technology will have to be developed. One of the problems will be the disposal of the large quantities of phenols and unsaturated hydrocarbons that are present. It is not definitely known to what extent unsaturated hydrocarbons have to be removed from the low-temperature fractions in order to produce satisfactory motor fuels. The possibilities of producing more stable compounds from them through such processes as oxidation or hydrogenation require further investigation. Satisfactory motor fuels, illuminating oils, and lubricants have been prepared from low-temperature tars on a laboratory scale. It remains to discover or invent processes by which the percentage yield of these can be increased and to devise means by which this can be done on a commercial scale so that the cost of production will be sufficiently low to enable competition with similar products derived from other sources.

Some of the fields now occupied by products obtained from high-temperature coal tars from the by-products coke and coal gas industry can also be satisfactorily served by similar products from low-temperature tars, as has been pointed out in a previous chapter; but in this case there is great danger of developing an over-supply. Even at the present time large quantities of ordinary coal tars, that could be used for these purposes if the demand were sufficiently great, are being burned in the crude state as a substitute for fuel oil in the steel industry.

CHAPTER IX.

AMMONIA-YIELD TESTS.

For purpose of comparison, determinations of ammonia yield from a number of typical coal and shale samples were made by the method developed and used in Scotland in connection with the examination of oil-shales.[1] This method consisted in heating 30 grams of coal or shale, crushed to 4-mesh size, in an iron pipe to bright redness for 1½ hours in the presence of a current of steam, and leading the gases into a flask containing an excess of dilute sulphuric acid. The ammonia fixed as ammonium sulphate in this solution. was afterwards determined in a manner similar to that used for the analysis of the ammoniacal liquor and sulphuric acid wash water from the carbonization tests.

The apparatus consisted of a piece of ¾-inch iron pipe, 28 inches long, set in a horizontal position in a furnace heated by four No. 3 Meker burners, as shown in figure 16. Both ends of the pipe were closed with corks and were cooled by means of cloth wrapped around them which was kept moist throughout the experiment to prevent excessive charring. Steam was introduced into the apparatus through a brass tube passing through the cork at one end. This end of the pipe was filled with pieces of previously-ignited fire-brick of about ¼ inch diameter. The 30 grams of coal or shale to be tested, crushed to pass a 4 mesh screen, were placed in the middle portion of the pipe. A glass tube passing through the cork at the opposite end served as an outlet for the vapors and gas generated. The other end of this tube was immersed in 100 c. c. of 2 N sulphuric acid contained in a 1-liter Erlenmeyer flask. This flask was placed in a large beaker filled with water. From it the uncondensed vapors and gases were led into a smaller empty flask which served as a trap for receiving any liquid that might be carried over. The permanent gases then escaped into the atmosphere through a thistle tube, the cup of which was filled with glass wool moistened with sulphuric acid.

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[1] Gavin. M. J., Hill. H. H., and Perdew. W. E Notes on the oil-shale industry, with particular reference to the Rocky Mountain district. U. S. Bureau of Mines. Reports of Investigations, Serial No. 2256, pp. 21-22, 1921.

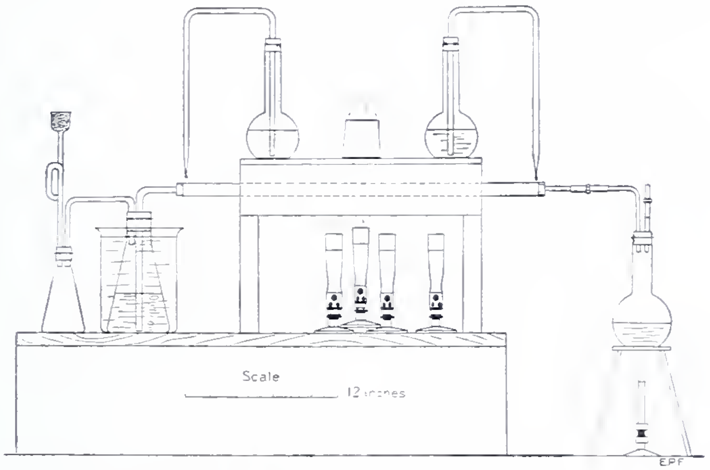

Fig. 16. Diagram showing apparatus used in the determination of ammonia yields.

In order to determine how rapidly and to what temperatures the charge was heated a preliminary heating of the apparatus was carried out with a base-metal thermocouple introduced into the middle of the iron pipe, instead of the coal or shale charge, with all other conditions the same as during a regular test. The temperatures recorded were as follows:—

At the end of 5 minutes, 900° F. (482° C.)
Steam introduced at the end of 5 minutes and continued to end of test.
At the end of 10 minutes, 1260° F. (682° C.)
" " " " 15 " 1370° F. (743° C.)
" " " " 20 " 1400° F. (760° C.)
" " " " 90 " 1535° F. (835° C.)

Throughout the tests as uniform a flow of steam as possible was maintained at a rate such that at the end of 1½ hours, the duration of the test, between 500 and 600 c. c. of liquid were present in the 1-liter flask.

At the end of the test, the thistle tube and small flask were carefully rinsed and the water added to the solution in the large flask, which was then filtered through a Buchner funnel and placed in an 800 c. c. Kjeldahl flask. It was made alkaline by the addition of concentrated sodium hydroxide solution. The ammonia was distilled off and collected in 100 c. c. of N/5 sulphuric acid solution. The excess acid was then titrated with N/5 sodium hydroxide solution and the amount of ammonia recovered from the 30 grams of sample was calculated. It was found that very small quantities of pyridine compounds were also present. The ammonia-yield obtained as above was corrected for these by treating the neutralized solution with 100 c. c. of sodium hypobromite solution, prepared as described in Chapter VI, and distilling off the pyridine into 25 c. c. of N/5 sulphuric acid solution which was then titrated with sodium hydroxide.

The table which follows shows the yields in pounds per ton, computed both as ammonia and ammonium sulphate, and the percentage of the total nitrogen in the original sample converted into ammonia. The percentage of the total nitrogen recovered as ammonia when the same samples were carbonized in the 3500-c. c. retort at temperatures of 900° and 1400° F., respectively, are also included, as well as the percentage of total nitrogen present in the original sample.

Yield of ammonia and nitrogen.

No. of sample	Character of sample	Total Nitrogen Per cent	Yield of ammonia Pounds p r ton	Yield computed as pure ammonium sulphate Pounds per ton	Total nitrogen recovered as ammonia Per cent	Total nitrogen recovered as ammonia in 3500-cc. retort To 900° F. (without steam) Per cent	Total nitrogen recovered as ammonia in 3500-cc. retort To 1400° F. (without steam) Per cent
35.	Cannel coal, Upper Kittanning	1.01	7.46	28.95	30	9	13
44.	Bituminous coal, Upper Freeport	1.58	8.58	33.28	22	----	15
93.	Bituminous coal, Brookville	1.54	6.10	23.66	19	4	18
93.	(Duplicate of above)	1.34	7.10	27.54	22	4	18
98.	Bituminous coal, Pittsburgh	1.28	10.24	39.72	33	13	23
98.	(Duplicate of above)	1.28	9.53	36.97	31	13	23
98.	Bituminous coal, Pittsburgh, without the use of steam)	1.28	4.87	18.89	16	13	23
102.	Cannel shale, Lower Freeport	.76	7.83	30.37	42	9	11
105.	Bituminous coal, Upper Freeport	1.62	12.25	47.52	31	6	14
106.	Bone, Upper Freeport	1.08	10.36	40.19	39	----	23
107.	Cannel shale, Upper Freeport	1.19	10.10	39.18	35	----	14
107.	(Duplicate of above)	1.19	9.15	35.49	32	----	14
107.	Duplicate (without the use of steam)	1.19	2.48	9.62	9	----	14
110.	Oil shale, Chattanooga	.74	10.48	40.64	58	9	17
110.	(Duplicate of above)	.74	9.68	37.55	54	9	17
115.	Oil shale, Green River Eocene	.69	8.34	32.55	50	9	11
115.	(Duplicate of above)	.69	7.82	30.33	47	9	11
115.	(Duplicate of above with silica tube substitute for iron pipe	.69	7.79	30.22	46	9	11
115.	Duplicate, (iron pipe without the use of steam)	.69	1.43	5.55	9	9	11
122.	Oil shale, Miocene	.49	7.63	29.60	64	----	20
	Spent material or residue from Test 105-2 Bituminous coal. Upper Freeport, carbonized to 900° F.	1.66	5.75	22.30	14	----	----
	Spent material or residue from Test 105-1, Bituminous coal, Upper Freeport, carbonized to 1400° F.	1.25	1.03	4.00	3	----	----

The foregoing experiments brought out the facts that the percentage of the total nitrogen that can be recovered in the form of ammonia from coals or shales under the same conditions of carbonization varies greatly with the character of the material and also that steaming the charge considerably increases the yield, but that this increase is much more pronounced in some materials than others. For example, the yield of total nitrogen from Pittsburgh coal was only doubled when steam was employed, all other conditions being the same; that of the cannel shale from the Upper Freeport horizon was increased nearly four times; and that of the oil shale from the Green River Eocene over five times. The yields from the iron tube with the use of steam were in almost every instance considerably greater than those obtained from the 3500 c. c. retort by dry carbonization, even up to temperatures of 1400° F.; but here again the contrast was greatest in the case of the cannel and oil-shales and least in the case of the bituminous coals. It was also found that when Upper Freeport coal was carbonized to only 900° F., considerable quantities of ammonia could still be recovered by further heating the residual coke in the presence of steam, although when the temperature had been raised to 1400° F., very little more ammonia could be obtained from the residue by this method.

CHAPTER X.

COMPARATIVE YIELDS OF OIL AND TAR FROM COALS AND SHALES, AND THE DISTRIBUTION OF THE NITROGEN AND SULPHUR AMONG THE PRODUCTS OF CARBONIZATION.

In order to compare and contrast the different types of vegetable debris constituting the organic matter of the various coal and shale samples tested in the 3500 c. c. retort, the yields per ton on a moisture and ash-free basis were calculated. This was done by dividing the yields of the carbonization tests carried to 1400° F. by the sum of the volatile matter and fixed carbon as determined by the proximate analyses. The results have been compiled in the following table:—

Yield per ton on ash- and moisture- free basis.

No. of sample	Character of sample	Volatile matter plus fixed carbon in original sample	Average yield per ton as shown by carbonization tests carried to 1400° F. in 3500 cc. retort.			Yield per ton computed on ash- and moisture-free basis.		
			Oil, (Gallons).	Gas, (Cubic feet).	Fixed carbon in residue Pounds based on proximate analyses).	Oil, (Gallons).	Gas, (Cubic feet).	Fixed carbon (Pounds.)
		Per cent						
35.	Cannel coal, Upper Kittanning	71.79	50.1	6,266	702	69.8	8,728	978
44.	Bituminous coal, Upper Freeport	91.40	24.1	8,749	1,127	26.3	9,572	1,233
93.	Bituminous coal, Brookville	88.05	24.7	8,949	1,071	28.1	10,070	1,216
98.	Bituminous coal, Pittsburgh	90.67	29.0	8,057	1,088	32.0	8,886	1,200
102.	Cannel shale, Lower Freeport	53.07	37.5	4,602	473	70.7	8,671	891
105.	Bituminous coal, Upper Freeport	90.70	23.8	9,828	1,100	26.2	10,836	1,213
106.	Bone, Upper Freeport	61.20	15.3	5,397	746	25.0	8,819	1,219
107.	Cannel shale, Upper Freeport	68.29	38.2	6,290	752	55.9	9,211	1.101
110.	Oil shale, Chattanooga	32.39	16.6	6,171	89	51.3	19,052	275
115.	Oil shale, Green River, Eocene	40.15	44.7	6.555	10	113.3	16,326	25
122.	Oil shale, Miocene	32.07	24.5	5,395	119	76.4	16,823	374

The bituminous coals contain organic matter yielding a relatively small volume of tar on low-temperature carbonization, a moderately large quantity of gas, and large quantity of fixed carbon. The cannel coals and shales, on the other hand, contain vegetable debris yielding between two and three times as much oil, somewhat less gas, and considerably less fixed carbon than the bituminous coals; the organic debris of the oil shales of the West yields still greater quantities of oil, also larger volumes of gas, and very much smaller quantities of fixed carbon.

The pages which follow show the quantities of nitrogen and sulphur in the original charge and the distribution of these elements in the various products of carbonization obtained from the tests carried out in the 3500 c. c. retort.

The following is a list of the test material used and the carbonization temperature of each test.

Test	
35-1	Cannel coal, Upper Kittanning 1400° F.
35-2	Cannel coal, Upper Kittanning 900° F.
44-1	Bituminous coal, Upper Freeport 1400° F.
93-1	Bituminous coal, Brookville 1400° F.
93-2	Bituminous coal, Brookville 900° F.
98-1	Bituminous coal, Pittsburgh 1400° F.
98-2	Bituminous coal, Pittsburgh 900° F.
102-1	Cannel shale, Lower Freeport 1400° F.
102-2	Cannel shale, Lower Freeport 900° F.
105-1	Bituminous coal, Upper Freeport 1400° F.
105-2	Bituminous coal, Upper Freeport 900° F.
106-2	Bone, Upper Freeport 1400° F.
106-4	Bone, Upper Freeport 1400° F.
107-1	Cannel shale, Upper Freeport 1400° F.
107-2	Cannel shale, Upper Freeport 1400° F.
110-1	Oil shale, Chattanooga 1400° F.
110-2	Oil shale, Chattanooga 900° F.
115-1	Oil shale, Green River Eocene 1400° F.
115-3	Oil shale, Green River Eocene 900° F.
122-1	Oil shale, Miocene 1400° F.

Quantity and distribution of nitrogen and sulphur.

Nitrogen	Test 35-1		Test 35-2		Test 44-1		Test 93-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	26.3529	--------	26.7318	--------	43.2762	--------	36.4279	--------
In residue	9.0376	34.3	18.5567	69.4	17.3399	40.1	19.6020	53.8
In oil	3.6834	14.0	3.6177	13.5	--------	--------	--------	--------
In tar	--------	--------	--------	--------	2.1674	5.0	2.2008	6.0
Recovered as ammonia	3.4767	13.2	2.2975	8.6	6.5777	15.2	6.6733	18.3
In gas by difference	10.1552	38.5	2.2599	8.5	17.1912	39.7	7.9518	21.9

Nitrogen	Test 93-2		Test 98-1		Test 98-2		Test 102-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	35.2286	--------	34.8992	--------	33.6512	--------	22.6024	--------
In residue	20.8078	59.1	21.9420	62.9	27.3461	81.2	6.0788	26.9
In oil	--------	--------	--------	--------	--------	--------	1.8437	8.1
In tar	2.0299	5.7	2.8097	8.1	2.7797	8.2	--------	--------
Recovered as ammonia	1.7238	4.9	7.8575	22.5	4.2483	12.6	2.5251	11.2
In gas by difference	10.6671	30.3	2.2900	6.5	none	--------	12.1548	53.8

Nitrogen	Test 102-2		Test 105-1		Test 105-2		Test 106-2	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	22.9026	--------	43.2135	--------	43.9344	--------	34.6702	--------
In residue	10.6173	46.4	22.8688	52.9	33.9968	77.4	14.3434	41.3
In oil	1.9408	8.5	--------	--------	--------	--------	--------	--------
In tar	--------	--------	2.0430	4.7	1.8018	4.1	1.5920	4.5
Recovered as ammonia	1.9679	8.6	6.0902	14.1	2.4800	5.6	8.0361	23.2
In gas by difference	8.3766	36.5	12.2115	28.3	5.6558	12.9	10.6987	31.0

Nitrogen	Test 106-4		Test 107-1		Test 107-2		Test 110-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	34.1064	--------	32.8381	--------	33.6294	--------	29.2966	--------
In residue	12.5250	36.7	15.7629	48.0	15.5329	46.2	7.2488	24.7
In oil	--------	--------	2.4484	7.5	2.2011	6.6	2.9566	10.1
In tar	1.6315	4.8	--------	--------	--------	--------	--------	--------
Recovered as ammonia	7.5774	22.2	3.7208	11.3	5.8218	17.3	5.1610	17.6
In gas by difference	12.3725	36.3	10.9060	33.2	10.0736	29.9	13.9302	47.6

Nitrogen	Test 110-2		Test 115-1		Test 115-3		Test 122-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	30.5139	--------	24.6227	--------	25.8302	--------	14.3546	--------
In residue	20.7415	68.0	1.9339	7.9	10.9499	42.4	3.9276	27.4
In oil	3.3377	10.9	10.8165	43.9	10.9447	42.4	1.7341	12.1
In tar	--------	--------	--------	--------	--------	--------	--------	--------
Recovered as ammonia	2.7451	9.0	2.6962	10.9	2.3348	9.0	2.8518	19.8
In gas by difference	3.6896	12.1	9.1761	37.3	1.6008	6.2	5.8411	40.7

Sulphur	Test 35-1		Test 35-2		Test 44-1		Test 93-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	58.7070	--------	59.5508	--------	44.6457	--------	123.6918	--------
In residue	31.6116	53.8	24.2524	40.7	27.9675	62.7	69.1515	55.9
In oil	1.9714	3.4	1.6182	2.7	--------	--------	--------	--------
In tar	--------	--------	--------	--------	1.5632	3.5	1.4291	1.2
In ammoniacal liquor	.4318	.7	.9001	1.5	.6384	1.4	1.3014	1.1
In gas by difference	24.6922	42.1	32.7801	55.1	14.4766	32.4	51.8098	41.8

Sulphur	Test 93-2		Test 98-1		Test 98-2		Test 102-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	131.4950	--------	71.4343	--------	68.8798	--------	46.9892	--------
In residue	96.0500	73.0	37.1186	52.0	39.2987	57.1	36.0386	76.7
In oil	--------	--------	--------	--------	--------	--------	1.3111	2.8
In tar	1.5430	1.2	2.5727	3.6	3.3974	4.9	--------	--------
In ammoniacal liquor	.6817	.5	1.5522	2.2	1.0228	1.5	.1239	.3
In gas by difference	33.2203	25.3	30.1908	42.2	25.1609	36.5	9.5156	20.2

Quantity and distribution of nitrogen and sulphur (cont'd.)

Sulphur	Test 102-2		Test 105-1		Test 105-2		Test 106-2	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	47.6133	----------	39.4790	----------	40.1376	----------	39.1644	----------
In residue	36.1440	75.9	21.4052	54.2	23.9616	59.7	24.7100	63.1
In oil	1.3343	2.8	----------	----------	----------	----------	----------	----------
In tar	----------	----------	1.3710	3.4	1.1384	2.8	.6449	1.6
In ammoniacal liquor	.0406	.1	.2658	.7	.3910	1.0	.0812	.2
In gas by difference	10.0944	21.2	16.4370	41.7	14.6466	36.5	13.7283	35.1

Sulphur	Test 106-4		Test 107-1		Test 107-2		Test 110-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	38.5276	----------	61.5369	----------	63.0198	----------	82.3472	----------
In residue	20.5410	53.3	36.3145	59.0	45.1680	71.6	49.8714	60.5
In oil	----------	----------	2.1720	3.5	1.0598	1.7	4.0937	4.9
In tar	.9706	2.5	----------	----------	----------	----------	----------	----------
In ammoniacal liquor	.7776	2.0	1.0826	1.8	.9946	1.6	.6231	.8
In gas by difference	16.2384	42.2	21.9678	35.7	15.7974	25.1	27.7590	33.8

Sulphur	Test 110-2		Test 115-1		Test 115-3		Test 122-1	
	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent	Grams	Per Cent
In original charge	85.7688	----------	41.7515	----------	43.7990	----------	144.4244	----------
In residue	53.0841	61.9	27.2898	65.4	35.2532	80.5	74.1880	51.4
In oil	3.8575	4.5	3.1498	7.5	3.8799	8.9	2.6412	1.8
In tar	----------	----------	----------	----------	----------	----------	----------	----------
In ammoniacal liquor	.7014	.8	.1850	.4	.1822	.4	.9722	.7
In gas by difference	28.1258	32.8	11.1269	26.7	4.4837	10.2	66.6230	46.1

CHAPTER XI.

LOW TEMPERATURE CARBONIZATION OF SEMI-BITUMINOUS COAL.

Subsequent to the completion of the foregoing report, a series of low temperature carbonization tests was made upon a sample of semi-bituminous coal from No. 10 mine of the Quemahoning Coal Company, half a mile west of Rockwood, Somerset County. This coal occurs at the Upper Freeport horizon. At the place where the sample was taken, the following section was measured:—

Section of Upper Freeport coal near Rockwood, Somerset County.	Inches
Gray shale	
Carbonaceous shale	1½
Coal	2½
Carbonaceous shale	⅛
Coal	7½
Carbonaceous shale	¼
Coal	9½
Carbonaceous shale	⅛
Coal	5½
Carbonaceous shale	1
Coal	4½
Carbonaceous shale.	

The tests were made in a 3500 c. c. vertical retort heated gradually to a 760° C. over an interval of eight hours. The apparatus and method of procedure were exactly the same as those used in the carbonization tests made upon bituminous coals from western Pennsylvania, which are described in Chapter VI.

The results of these tests are tabulated below:—

Proximate analysis:

Moisture	.4
Volatile matter	20.1
Fixed carbon	65.6
Ash	13.9
Nitrogen	1.02
Sulphur	1.13

Carbonization test:

(Computed on basis of 2000 lb. raw material.)

Volume of low-temperature tar	9.2	gallons
Light oil recovered from gas	.6	gallons
Ammoniacal liquor	5.8	gallons
Ammonia	3.87	pounds
Calculated as ammonium sulphate	15.01	pounds
Weight of residue	1,682	pounds
Volume of gas, saturated with water, at 60° F. and 30-in. mercury	12,935	cubic feet

Distillation of low-temperature tar from Upper Freeport semi-bituminous coal.

Specific gravity of dehydrated oil, 1.0664

Sulphur .... .32 per cent

Nitrogen .... .46 per cent

Air distillation, barometer 29.314 in., first drop 48° C.

Temperature Degrees C.	Per cent by volume distilled	Sum, Per cent	Per cent cut	Sp. gr. of cut
Air distillation to	trace	trace	12.08	.8561
50 to 75	1.27	1.27		
75 to 100	2.27	3.54		
100 to 125	.47	4.01		
125 to 150	2.07	6.08		
150 to 175	6.00	12.08		
175 to 200	7.07	19.15	13.74	.9487
200 to 225	6.67	25.82		
225 to 250	14.93	40.75	20.46	.9982
250 to 275	5.53	46.28		
Vacuum distillation at 68 mm.				
To 200	.67	.67	19.66	1.0771
200 to 225	2.00	2.67		
225 to 250	2.33	5.00		
250 to 275	7.33	12.33		
275 to 300	7.33	19.66		
Residuum by difference	34.06		34.06	1.1874

Carbon residue of residuum (Conradson method) 21.2 per cent.

Composition of air distillation fractions, in per cent by volume.

Fraction, Degrees C.	Crude oil	Sp. gr. fraction at 15.56° C.	Tar acids in fraction removed by 10 per cent sodium hydroxide sol.	Tar bases in fraction removed by 20 per cent sulphuric acid solution	Neutral oil in fraction	Neutral oil removed by 95 per cent sulphuric acid	Neutral oil removed by 98 per cent sulphuric acid	Saturated hydro-carbon in fraction
Light oil from gas	----------	.7661	1.5	.5	98.0	37.0	56.5	12.6
To 175	12.08	.8561	9.0	.5	90.5	51.0	66.0	0.8
175 to 225	13.74	.9487	33.5	1.8	64.7	53.0	65.5	[illegible]
225 to 275	20.46	.9982	15.5	2.0	82.5	68.0	79.5	[illegible]

Composition of residue from carbonization test.

Moisture	.3
Volatile matter	3.1
Fixed carbon	79.6
Ash	17.0
Nitrogen	.82
Sulphur	.90

Character of residue: Hard, porous coke with metallic luster.

A comparison of these results with those obtained from the bituminous coals of the western part of the State brings out the following interesting facts:—

The volume of low-temperature tar per ton yielded by semi-bituminous coal is considerably less than that from bituminous coal. Four typical bituminous coals gave an average yield of 25.4 gallons per ton, the maximum being 29 gallons and the minimum 23.8 gallons. This is 2.8 times the quantity obtained from the semi-bituminous coal. The average specific gravity of the tar from the bituminous coal was 1.0190, which is somewhat lower than that from the semi-bituminous. An average of 2.4 gallons of light oil per ton was recovered from the bituminous coal, or four times as much as that obtained from the semi-bituminous. The average yield of ammonium sulphate per ton was 23.65 pounds from bituminous coal and only 15.01 from semi-bituminous. On the other hand, the yield of coke and gas was greater for the semi-bituminous than for the bituminous coal.

The sum of the air distillation fractions to 275° C. was approximately the same for the two types of coal tars. The vacuum fraction from the residue to 300° C. was considerably less in the case of the semi-bituminous, and the pitch residue was considerably greater. The various fractions from the semi-bituminous tar had somewhat higher specific gravity than the corresponding fractions from the bituminous. Also, the air distillation cuts from the former had a considerably lower content of tar acid or phenolic compounds.

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